THE BOOK OF THE MICROSCOPE

By A. FREDERICK COLLINS

THE BOOK OF THE MICROSCOPE
THE BOOK OF WIRELESS TELEGRAPH AND TELEPHONE
THE BOOK OF STARS
THE BOOK OF MAGIC
THE BOOK OF ELECTRICITY
GAS, GASOLINE AND OIL ENGINES
THE AMATEUR CHEMIST
THE AMATEUR MECHANIC
HOW TO FLY
THE HOME HANDY BOOK
KEEPING UP WITH YOUR MOTOR CAR
MOTOR CAR STARTING AND LIGHTING

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A WORD TO YOU

So this is *The Book of the Microscope!*

You are living not only in a world of three dimensions but in three worlds in one, though you may not realize it. These three worlds are (1) the world of the infinitely big and far away; (2) the world of ordinary sized things which is all around and about you, and (3) the world of the infinitely small, which is also at hand but hidden from your sight.

The first of these three worlds is made up of the heavenly bodies and to see them to the best advantage you have to use a *telescope;* the second world is the one that you really live in and the things in it are of such magnitude you can see them with your *naked eye,* while the third and last world is formed of the most wonderful objects imaginable, but you must have a *microscope* with which to see them. It is this world of the infinitely small that I have told you about in this book, and it is ready and waiting for you to explore it.

Wherever there is a barrel of rain-water, a pool, or a brook you will find microscopic specimens of plant and animal life galore and you

have only to examine these with a microscope to see how fearfully and wonderfully they are made. Every plant and flower and tree that grows will take on a new meaning if you will look at them through a microscope. Animals of all kinds from the lowest form, called the *Ameba,* on up through the scale to the highest form, called *man,* make highly interesting and instructive objects for examination with a microscope—but of course you can examine only a very small portion of these at a time.

Then there is what is called the *inorganic* world—that is the rock and minerals and metals of which the earth's crust is made and to examine these under a microscope and learn about them is to gain an insight into nature that is in itself a liberal education. And, finally, there is the food, drink and household articles, such as fabrics and paper, that provide objects which you ought to examine with a microscope for the benefit and behoof of the health and the exchequer of your family.

I have arranged the contents of this book so that if you will examine the objects in the order named you will have in the end a working knowledge of not only the microscope itself but the elementary principles as well of botany, zoölogy and histology and of the structure of the materials that make up the inorganic world.

You do not need an expensive microscope

with which to explore the world of the infinitely small, for one costing ten dollars or less will do, though of course the better the instrument the more and the clearer you will be able to see. An inexpensive microscope can be bought of the L. E. Knott Apparatus Co., Boston, Mass., or of the Palo Co., 90 Maiden Lane, New York City. Better instruments can also be bought from these firms and of the makers, Bausch & Lomb Optical Co., Rochester, N. Y., and the Spencer Lens Co., Buffalo, N. Y.

You can buy any living plant or animal specimen of the lower forms that I have described in this book, and dozens of others, of the Cambridge Botanical Supply Co., Waverly, Mass., Powers & Powers, Lincoln, Neb., and the New Jersey Entomological Co., South Amboy, N. J. As for the higher forms of plant and animal life you can buy specially prepared sections mounted on slides from the first named supply houses and all of them issue price lists and catalogues and you should by all means get copies of them. At any rate get a microscope and the rest will come in easy stages.

A. Frederick Collins

The Antlers
Congers, New York

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THE BOOK OF THE MICROSCOPE

CHAPTER I

WHAT WE CAN SEE WITH A MICROSCOPE

As you probably know, the microscope (pronounced *mi-kro-skop*) is a lens, or a combination of several lenses, which magnifies the images of objects that are (1) too small to be visible to the naked eye, or (2) whose details are so indistinct that they cannot be seen by the naked eye. The extent to which a microscope will magnify depends on several factors and these will be explained in good time.

The Invention of the Microscope.—Like all other scientific instruments, the microscope has passed through a long period of development, and it is hard to believe that the compound microscope as we know it to-day is the outcome of the *flea glass* which was in use when Columbus set sail on his first voyage of discovery.

The Flea Glass.—The flea glass,[1] which was a simple convex lens, was so called because the

[1]The Latin name for the flea glass was *vitra pulicaria*, which sounded better.

intellectual giants of those latter medieval days used it to observe such small insects as the flea, the louse, and the mite. When they saw the enlarged images of these innocent parasitic creatures of man and beast, and found they were such terrible looking objects, they were scared almost out of their senses. The flea glass had a magnifying power of from six to ten times, and it is well for those who used it that it was not higher.

The Compound Microscope.—Two or more lenses were first used together some time between 1590 and 1609; this was done independently by Hans and Zachias Jansson (father and son) who were Dutch spectacle makers, and Galileo, the greatest scientist of his time. These early compound microscopes had a double convex lens for the object glass and another like lens for the eyepiece.

These lenses were mounted in a tube more than a foot long and in this crude state the microscope remained until the end of the eighteenth century. In the beginning of the nineteenth century, however, there was a fresh outburst of enthusiasm concerning things scientific, and the microscope has been constantly improved upon ever since, until now it is one of the most highly developed and valuable instruments in the service of mankind.

The Kind of Microscope You Want.—From what you have just read you have gathered that as far back as Galileo's time there have been two kinds of microscopes: (*a*) the simple magnifying glass, or *magnifier,* as it is called, and (*b*) the compound microscope; both kinds are in use at the present time.

There are, however, several modifications of these, and the kind you want depends on what you want to see and do with it. A magnifier will be found useful for obtaining magnifications of the image of an object of from four to twenty-five times, while for higher powers you will need a compound microscope; this will give you a magnified image of the object of from 25 to 1,000,000 times.

What You Can See with a Magnifier.—Any kind of a convex lens will serve as a magnifier, but a lens made especially for the purpose is better because you can see the object more clearly and there is less distortion. Take any kind of a magnifier and look at the printed letters on this page and you will at once be struck with the fact that they are greatly enlarged and stand out very boldly; but you will also see that, instead of their edges being sharp and clear cut as they appear to the naked eye, they are rough and uneven.

Then examine the paper and you will observe that it is not at all as smooth as your naked eye

would have you believe, but instead is very coarse. A most striking example of the enlarging power of a magnifier is to look at the skin of your hand with one, especially the cuticle around your finger nails, and you will be

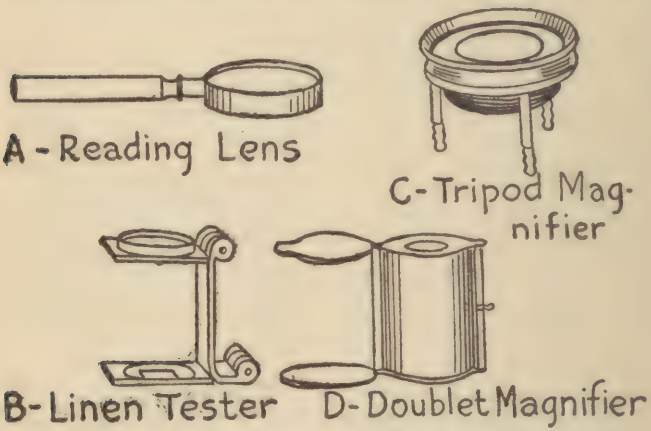

FIG. 1.—KINDS OF MAGNIFIERS

surprised, and probably shocked, to see the condition in which it is.

This done, take a look, like the learned man of old, at a flea, an ant, or any other minute animal and you will see why the ancient observers were amazed and described the flea in terms that threw the prehistoric *plesiosaurus* [2] and modern sea serpent in the shade. And so also with nearly every object you examine. A lens with a magnifying power of only four

[2] A long-necked marine reptile of the dim long ago.

times will reveal a strange and wonderful world about you that you would scarcely imagine existed.

Nor is a magnifier an instrument intended merely for pleasure—no, indeed, for it is useful, and often indispensable, in many and diverse ways. So useful, in fact, is it that it is made for special purposes, as for instance the *reading glass* as shown at *A* in Fig. 1, which enables people with dimmed eyesight to read printed text and handwriting, while sleuths of the Sherlock Holmes variety employ it for examining fingerprints, tracks of man and beast, and other details too small for the naked eye to see.

Then there is a little magnifier called a *linen tester* (see *B* in Fig. 1) which was originally used for counting the threads of fabrics, but which is now employed for all manner of purposes where a low power will suffice. Another magnifier (see *C* in Fig. 1) consists of a double lens and is known as a *tripod magnifier.* It has a magnifying power of seven or eight times; this is enough for elementary school work, such as examining seeds and making similar observations. A more powerful glass is the *doublet magnifier,* shown at *D,* its magnifying power ranges from six to 24 times. The great advantage of a doublet is that it gives excellent defini-

tion and an exceptionally flat field with a long focal length.

A magnifier is also useful in examining the works of watches, the condition of jewelry, especially the mountings, and also of gems; any imperfections in the latter such as flaws, cracks, etc., are immediately discernible through a magnifier when to the naked eye they appear quite perfect. In almost every line of business and in nearly every industry the magnifier in one form or another is used as a tool of trade.

In the beginning of the text under the present caption I suggested that you should examine your nails with a magnifier, I will add here that it is equally as serviceable in examining the eyes, the teeth and the throat. It is a wonderful aid in locating foreign particles in the eye. The lower the power of the magnifier the easier it will be to find the offending particle, provided it is large enough to be readily seen; conversely, the higher the power of the magnifier the harder it will be to find it, but once having found it the better you can see it.

What You Can See with a Microscope.—After you have used a magnifier for awhile and then change over to a compound microscope (*A* and *B*), you will have another surprise in store, for instead of seeing the image of an object magnified a few times, you will see it magnified a hundred, a thousand, or a million times according

to the power of your instrument. This being true, you cannot look at an object as large as a flea all at once, but you have to examine it piecemeal, that is, a small portion of it at a time.

FIG 2A.—USING THE MICROSCOPE

Suppose you want to learn the mechanism of the different parts of a cricket or a fly, or a flea. The first thing you have to do is to dissect it, that is, you cut it up very carefully and take the part of its anatomy you want to learn about, say the gizzard of the first, the proboscis of the second, and the *pygidium*[3] of the last, mount it

[3] This is the last, or posterior, dorsal segment.

and then study it under the best possible conditions of light and power.

Home Uses of the Microscope.—What I have just told you about examining the parts of little animals with a compound microscope was in-

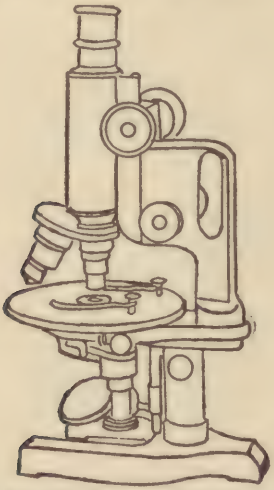

FIG. 2B.—COMPOUND MICROSCOPE

tended to bring out the difference in the power of the former instrument and that of the magnifier, for there are many other branches of microscopy (pronounced *mi-kros'-kop-y*) that are just as important, if not more so, for instance, the examination of everyday substances.

If every home had a compound microscope

in it, there would be far less sickness than there is now, for the two chief things which derange the human organism are (1) impure water, and (2) impure food. The constant use of a wide variety of these essential to life has made us careless as to their condition and quality, but since disease often lurks in them it behooves all of us to combat it by the simple and highly interesting expedient of making a microscopic examination of them.

Then there is the matter of fabrics. With a very low power microscope you can see exactly what kind of fibers a piece of goods is made of and how it is made. It may be *all wool* and have the proper *feel*, and look all right to the naked eye, but it makes a very considerable difference in the *wear* of it whether it is made of short or long fibers and this the microscope will quickly show. Again, since artificial silks have come into common use, it is well to know whether you are getting the fiber produced by the silkworm or that manufactured from cellulose.

Educational Uses of the Microscope.—While it is a source of much pleasure, and you can also learn considerable about the structure of plants and animals, or *biology*, as these two branches of science when combined are called, by examining them haphazard with a microscope as you come to them, it is a far better

plan to do so in a systematic way, for then you will get what might be called a *working knowledge* of these great and far-reaching subjects that will be of real educational value.

The Examination of Plants.—That branch of biology which treats of plant life is called *botany,* and the easiest and best way to learn how various plants are built up is to begin with one of the *Algae* (plural of *Alga*), which are among the lowest forms of plant life. They are sometimes incorrectly called *"frog-spittle."* Having discovered the nature of the algal structure, that is, how the algae are built up, you go on to the next higher forms which are the *Fungi* (plural of *Fungus*) to which group the mushrooms belong.

Then you take up the mosses, or *Musci,* to give them their scientific name, next the ferns, or *Filicales* and follow this with an examination of the family of pine tree, or *Gymnospermae,* which were the first real trees that appeared on the earth's surface. Finally, you examine the flowering plants and all of the flowering trees or *Angiospermae,* which constitute the highest form of plant life.

An examination of the leaves, the buds, the pollen, the stamens and the cross sections of these plants will fix in your mind for all time the difference between them, and in another

chapter I will tell you how to prepare and examine each one in order.

The Examination of Animals.—After you have made a microscopic examination of the different groups of plants, you can then take up the various groups of animals, or *zoölogy,* as it is called, and learn how the several parts of them are built up. This you can do by starting with the *Amoeba* and going on up step by step to, and including, man, which is the most complex of all the life forms.

Just as the Algae are among the lowest forms of plant life, so the Amoeba is one of the lowest forms of animal life, and belongs to the phylum, called *Protozoa.* After you have studied it with your microscope you take a higher form, the sponge, which is a member of the *phylum, Porifera.* Next you look into the structure of the *Hydra,* of the *phylum, Coelenterata;* then into flat, round and true worms of the *phyla: Platyhelminthes, Nemathelminthes* and *Annelida,* and this will bring you to the highly interesting *Arthropoda phylum,* which includes the insects such as moths, butterflies, and beetles.

Having learned the nature of the structure of these you are ready to begin your examination of the highest order of animals which go by the family name of *Chordata* (pronounced *cor-dá-ta*) and which includes all of the animals that have notochords and backbones. It is in

these latter examinations with the microscope that you see how the nerves, muscles, brain, blood, heart, lungs, liver, stomach and kidneys are built up of cells, all of which is wonderfully fascinating work.

Technical Uses of the Microscope.—While you can study all of the foregoing objects with an $8 or $10 microscope, a better one will naturally give you a higher magnification and a clearer field. But if you are going to be a real microscopist (pronounced *mi-krós-ko-pist*) and do technical work, you must have a good high power instrument and this will cost you from $25 up to $250, depending very largely on the state of your finances and the class of work you are going to do.

The Microscope in Health and Disease.—During the latter part of 1600 the microscope had been sufficiently improved so that microscopists began to find out how plants and animals were built up. Leeuwenhoek, a Dutch investigator, made a microscope, and with it he discovered that there were enormous numbers of minute living things in the saliva of the mouth, in water and in matter that was decomposing. He called these microscopic forms of life *animalcules* and these have since been given the name of *bacteria,*[4] and are the very lowest forms of plant life.

[4] The singular of which is *bacterium.*

Hooke, a botanist of England, found that cork was composed of minute cells, and following came Malpighi and Swammerdam who observed that insects also had a cellular structure. In the early part of the nineteenth century the microscope was greatly improved upon and with it Schleiden and Schwann were enabled to work out the theory that all plants and animals are built up of microscopic particles of living matter called *cells*.

Then Leeuwenhoeck's animalcules were studied with the higher power microscopes that had been devised, but it was not until the eighties of the nineteenth century that Koch and Pasteur founded the science of *bacteriology*. The bacteria are one-celled plants that multiply by division; some of them are helpful to man and others are very harmful. The good little bacteria are simply scavengers that live upon dead matter while others are parasites and consume the living flesh of the higher animals. In doing this they give off poisonous matter which in turn produces diseases of various kinds.

The Microscope as a Legal Aid.—I have previously mentioned that the magnifier serves as an aid in the investigations of the detective and often plays an important part in determining some mooted legal point. One of its uses is in finding the direction a bullet took when it

was fired and the distance from which it was fired, both of which are obtained by examining the wound. Other details concerning the bullet and powder that were used are revealed by the microscope.

As a supplemental aid to the *Bertillon system*[5] of measurements, the microscope is used to identify criminals and others by means of impressions left by the fingers. The ridges and furrows on the finger tips remain the same all through life, nor can they be changed by any known means. The microscope is also largely used in determining whether or not a signature or other writing is a forgery. Finally it is often used to prove whether blood stains are those of a human being or of some lower animal.

The Microscope in Chemistry.—The use of the microscope in chemistry, or microchemistry, as it is called, has not been very extensive in time past, but the value of it in the study of crystals is well known; it is also being applied to the study of reactions and chemical analysis. The formation of crystals in a solution can be observed while the process is going on and the minute crystals thus produced in many solutions often show the most remarkable characteristics.

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[5] This is a system of measurements and records thereof of man and includes personal characteristics. It is used as a means of identification.

The advantage of using the microscope for observing the change in the condition of chemical reactions is that (1) only a very minute amount of the substance, or substances, need be used; (2) the ease with which the substances are prepared—it is only necessary to place a drop on a slide; (3) the short time required for the operation; and (4) the small amount of apparatus necessary to work with.

The Microscopic Study of Minerals and Metals.—There are numerous tests used to identify minerals, but the best way is to examine them with the microscope. To examine a mineral it must be cut into slices sufficiently thin so that the light will pass through it and then every detail of its structure can be clearly seen when it is illuminated by refracted light. This forms a more simple means of identification than chemical analysis. The study of minerals with the microscope is called *petrography.*[6]

The microscope is also used extensively in the industries for examining the structure of metals and their alloys, and hence this branch of microscopy is called *metallography.*[7] In making these examinations the metal is polished and the surface is obsered by *reflected*

[6] *Protrology* is the science of rocks and *petrography* is that branch of protology which includes the minerological and chemical characteristics of rocks.

[7] The science that treats of metallic substances.

light. The microscope not only shows the structure of various metals and alloys, but also whatever impurities there may be in them. The hardness of steel can easily be learned with the microscope as its hardness depends on the amount of carbon in it.

CHAPTER II

YOUR EYE AND THE ACTION OF LENSES

Nearly all of the gifts which nature has bestowed upon us are so familiar, by virtue of the fact that we have them with us from the time we are born, that we are too often prone to consider them as mere commonplaces, and hence seldom take the trouble to investigate them. The greatest of these, and the one to which we give, as a rule, the least thought and attention, is *light,* and which, as you will see shortly, is of the greatest importance in the needs of our everyday lives.

Light, the Essential of Life.—The chief source of light to which the earth, and all that is in and on it, owes its very existence, is our sun. This gigantic luminary, although it is 93,000,000 miles away from us, sends out its light and heat waves through the ether,[1] and these travel at the rate of about 186,000 miles a sec-

[1] The ether is an elastic medium that fills all of the spaces in the universe which are not otherwise occupied by gross matter. It is by, in and through the ether that light and all other electromagnetic waves and disturbances are set up and transmitted.

ond. Without light and heat the earth would be enveloped in absolute darkness and it would be intensely cold—so cold that life in any form could not exist, much less thrive, on it.

Light is not only an essential of life but it also provides us with the connecting medium between objects and our eyes so that we can *see* them. This ability of our eyes to *sense* the size, shape, color and distance of external objects is called *sight,* and it is this particular phase of the action of light on our organs of sight in which we are interested in just now.

Light, Sight and Your Eye.—The ancient philosophers knew that light traveled in straight lines, but what they did not know is that the eye is able to see some objects by the light they set up and other objects by the light that is reflected by them. It was centuries later that the way light really acts and the eye really sees was learned, and as these have to do with the use of the microscope it is useful to get them clearly in your mind.

Your Eye, the Organ of Sight.—Now, although the eye itself is a complicated piece of mechanism, it is easy to understand how it works when it *sees things,* for it is made very much like a little camera. If you will take a look at Figure 3, which is a cross section through the human eye, you will see that the

chief parts of it are formed of (*a*) the *cornea,* (*b*) the *iris,* (*c*) the *lens, and* (*d*) the *retina.*

The cornea is a tough, transparent film that protects the iris and the lens, and it fits over these as a crystal fits over the face of a watch. The iris, which is formed of a thin membrane with a hole in it, corresponds to the diaphragm

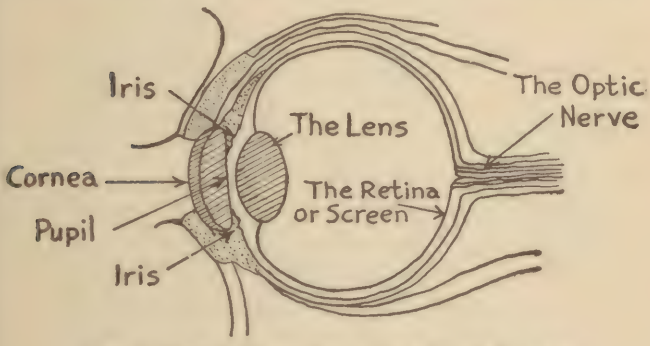


FIG. 3.—SECTION THROUGH THE HUMAN EYE

of a camera and its purpose is to let in the exact amount of light that is best suited to its needs. The hole in the iris forms the *pupil;* this is automatically made larger or smaller according to the amount of light the eye needs.

The lens of the eye is *doubly convex,* and is like that of a camera. It is through, and by means of it that the rays of light of an object are brought together and thrown upon the *retina,* which is a sensitive screen at the back of the eye. When the rays of light from the

object pass through the lens they are *focused* on the retina and in this way a picture of the object is formed on it. The *optic nerve*, which is connected with the retina, leads to the brain, and as the rays of light fall on the retina they set up a photochemical reaction, something like that which is set up on a camera film. This reaction gives rise to the nervous impulse which then travels over the optic nerve to the brain, where the object is *visualized*, or as we say it in everyday language, we *see it*.

Since your eye, with which you see, is made up of a lens as one of its chief parts, it is both fitting and proper that you should examine into the action of light as it passes through a convex lens as well as other kinds of lenses. Moreover, there are a large number of instruments which are used to aid the natural lens in the eye and which produce an enlarged image of an object or enable us to *see* it more distinctly and these are all formed of one or more lenses.

Various Kinds of Lenses.—Every one is familiar with the most common kind of lens which is known as a *magnifying glass;* this is a *double convex lens* like that of the eye. Besides this there are several other kinds of lenses, all of which are shown in Figure 4. Lenses can be divided into two general groups (*a*) *convex lenses*, and (*b*) *concave lenses*. Named in their usual order the various lenses are (1) the

double convex, (2) the *plano-convex,* and (3) the *converging meniscus.*[1] All of these lenses have at least one surface which curves outward. Then there are (4) the *double concave,* (5) the *plano-concave,* and (6) the *diverging meniscus.* And all of these have at least one surface which curves inward.

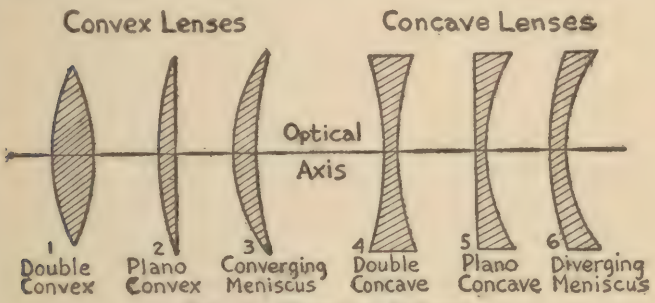


FIG. 4.—TYPES OF LENSES

While all of these lenses are largely used in the construction of various optical instruments to enable the eye to see the better, the chief one that concerns us in microscopy is the double-convex lens. To understand how the microscope forms enlarged images of objects you must know how a ray of light acts in passing through a convex lens. Once that you get this clear in your mind you will have the basic principle of the whole thing in a nutshell.

Kinds of Rays of Light.—Before going into the effect a lens has on a ray of light when passing through it, let us find out a little more about

light itself. First of all there are two ways in which rays of light may travel through space and these are (1) as *parallel rays,* such as are given off by the sun, and (2) as *divergent rays,* such as are given off by a lamp, or any small and close source of illumination. These different kinds of rays are shown at *A* and *B* in Figure 5.

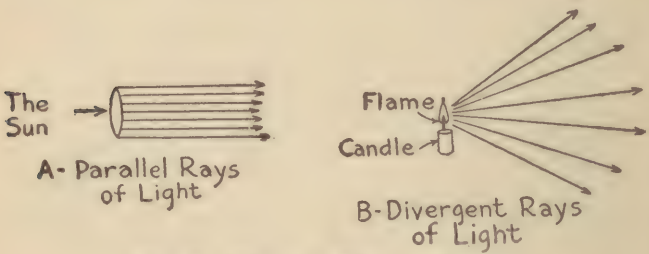


FIG. 5.—KINDS OF RAYS OF LIGHT

A large number of rays of either kind is called a *beam,* or a *pencil,* of light; when this passes through a double convex lens both parallel and divergent rays are affected in the same way, that is, they are *bent* out of their original direction, and this bending, or *refraction,* of the rays, as it is called, takes place *downward* toward the center of the *optic axis.*[2]

To see just how and why this happens, let us take the case of a single ray of light passing through a prism, since a double convex lens acts

[2] This is a line drawn through the center of a lens and at right angles to its diameter as shown in FIG. 4.

much in the same way as though it were formed of two prisms with their bases cemented together as shown at *A* in Figure 6.

How a Prism Refracts Light.—A ray of light is made up of light waves and these move in the same direction as the ray. A ray is formed of transverse vibrations in the ether, or light

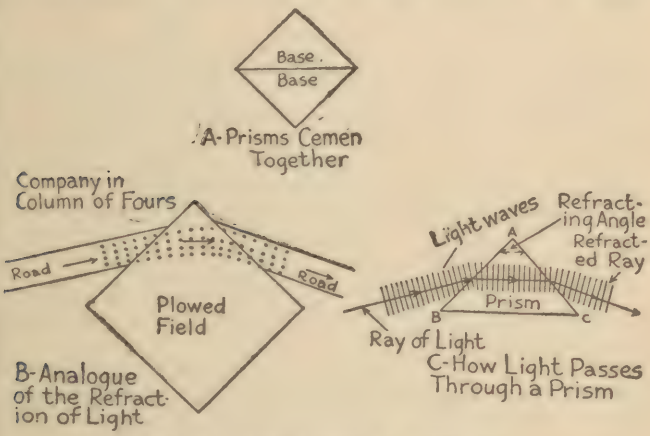


FIG. 6.—HOW LIGHT IS REFRACTED

waves, as they are called, and they are parallel with each other so that their fronts are at right angles to the ray. Thus the ray of light may be thought of as a company of soldiers marching in a column of fours as shown at *B*.

If such a column were to march from a smooth road into a roughly plowed field, the soldiers, as they entered the field one by one, would be slowed down, or *retarded,* and as a re-

sult of this slowing down the column would execute a nearly perfect half-right face. Upon emerging from the field just the opposite action would take place and the soldiers on reaching the smooth road would speed up, or be *accelerated,* with the net result that the direction of the march would again be bent, all of which is closely shown at *B*.

A ray of light with its perpendicular waves passing from the air into a prism, as shown at *C,* will be bent, and for the same reason, as explained above in connection with the soldier analogue, as it advances into, or emerges from, the prism. This bending of the ray out of its straight course is called *refraction;* it is this property of a lens that enables it to form images of objects on the retina of the eye or on any other suitable screen.

Real and Virtual Images.—An image of an object is a picture of it and this may be either (1) a *real image,* or (2) a *virtual image.* The difference between these two kinds of images is that a real image will project a picture on a screen while a virtual image will not. In other words, a virtual image is one that the eye sees as if it really existed but which as a matter of fact does not exist.

To project a real image on a screen all you need to do is to hold a convex lens close to a sheet of white paper, or, better, white card-

board, and in a line with the object, to serve as a screen on which to catch the image. By moving the lens to and from the white surface you will be able to obtain a sharp picture, or image, of the object. This process is called *focusing.*

Moreover, you will observe that this image is *inverted,* that is, it is upside down on the surface which is now called a *screen.* This is because the rays of light from the object in passing through the lens are refracted so that those from the top of the object after emerging from the lens are bent downward, cross the optical axis and are projected at the bottom of the screen.

Likewise those rays that come from the bottom of the object are bent upward and appear at the top of the screen. Those rays that come from the middle of the object and which pass through the center of the lens are not bent, or refracted, because the light waves of which the ray is composed are not slowed down on entering and leaving the lens. How a lens forms a real image is shown in Figure 7.

The Focus of a Lens.—When parallel rays of light, as those from the sun, pass through a convex lens they are refracted and cross at a point on the optic axis. This point is known as the *principal focus* (see *A* in Figure 8); it is the point at which the sun's rays are the hottest

when a convex lens is used as a burning glass.

It is clear that with a double convex lens there can be a principal focus on either side of it, and this depends on which side the source of light is. The distance of either of the principal *foci*[3] from the center of the lens is known as

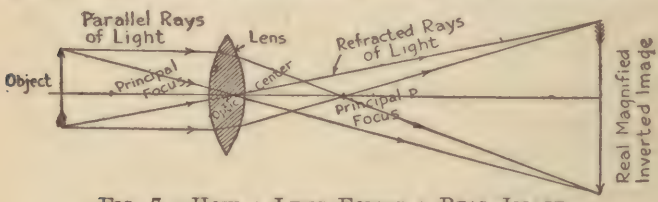


FIG. 7.—HOW A LENS FORMS A REAL IMAGE

the focal length; this can easily be determined by using it as a burning glass.

How the Focus Affects the Image.—Now the principal focus of a lens and the relative position of the object to the former is of great importance in the formation of the images. You have just seen how, at *A*, in Figure 8, parallel rays, when they pass through a lens, converge and meet at a point. On the other hand, if an object is placed at this point, or principal focus, the rays from the object will, upon emerging from the lens, be parallel and, consequently, will not focus; this is likewise shown at *A*. What occurs when an object is placed beyond the principal focus of a lens is that the rays are

[3] Plural of *focus*.

brought to a focus *beyond* the principal focus as shown at *B*, on the other side of the lens.

The nearer the object is brought to the prin-

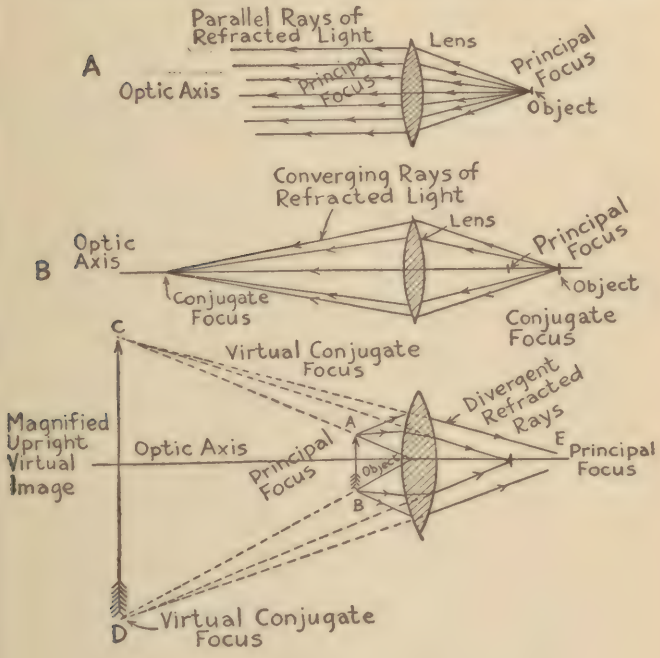


FIG. 8.—THE ACTION OF LENSES ON LIGHT

cipal focus the farther away will be the point at which it focuses on the other side of the lens, and, as you have just seen, when the object is placed at the principal focus the rays are never brought to a focus on the other side, since they

emerge as parallel rays. From this you will gather that there must be two points on the optical axis of a lens so that if the object is at one point the focus will be at the other point. These two points are called the conjugate foci of the lens.

How to Find the Focal Length of a Lens.—If the object is placed at a distance from the principal focus which is equal to the focal length of the lens (in other words, at a distance of twice the focal length from the lens), then its conjugate foci will be twice the focal length from the lens on the other side. Thus, when the image and the object are equidistant on either side of the lens, they must be equal to each other in size and four times the focal length of the lens apart.

The above fact is very useful in determining more accurately than the way I previously told you to use in finding the focal length of a lens. To do so by this method place the object in front of the lens with the screen back of it and adjust the position of the object and the screen until the image and the object are of the same size. Then measure the distance of the object from the screen and divide it by four; this will give the focal length with a fair degree of accuracy.

How Virtual Images Are Formed.—I have already explained how a real image is formed

and how it can be thrown on a screen. If, however, the object is placed *between* the lens and its principal focus the rays emerging from the other side of the lens will be *divergent,* as shown at *C,* and, hence, can never meet in a focus on that side of the lens.

But if these divergent rays are traced backward as shown by the dotted lines, it will be found that they come to a focus somewhere back of the principal focus of the lens and, consequently, on the same side of the lens as the object. This point is called the *virtual conjugate focus* of the lens. Now place your eye in the vicinity of the divergent rays at *e* and *f* when they are converged by the lens of the eye and brought to a focal point on the retina. You will then see the enlarged image *c* and *d* of the object *a* and *b*.

To prove that this is a *virtual image* all you need to do is to place a screen where your eye was when you saw the image and you will find that the image will not be thrown on the screen. Farther, you will readily see from the diagram why a virtual image is an upright and not an inverted image as is a real image. Having firmly grounded the above principles in your mind, for they are the fundamentals of optics, let us next consider two defects which crop out in the use of lenses for aiding the eye; namely,

(1) *spherical aberration,* and (2) *chromatic aberration.*

What Spherical Aberration Means.—While it is true that all of the rays of light in passing through a lens are refracted to nearly the same degree, nevertheless, there is just enough difference in the degree of refraction of each ray to cause them to meet at various points along the optical axis instead of at a single focal point on it.

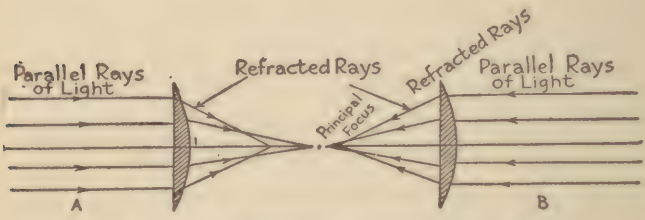


FIG. 9.—HOW SPHERICAL ABERRATION IS CAUSED

This difference is known as *spherical aberration,* and in working with a microscope it is very annoying, as it prevents you from getting an absolutely sharp focus, which of course is necessary to clear vision and accurate observations. How spherical aberration occurs when parallel rays of light strike first the flat and then the curved surface of a plano-convex lens is shown at *A* and *B* in Figure 9. From these diagrams you will observe that the aberration is greatest when the light strikes the flat side first, and least when it strikes the curved side

first. From this you will see that the *amount* of spherical aberration is due to the shape of the lens, and it follows that it is least in a double concave lens.

What Chromatic Aberration Means.—White light, such as the light from the sun, may be broken up, by passing it through a prism into seven different colors which, when blended together, act on the retina of the eye and give us through the optic nerve the sensation of white

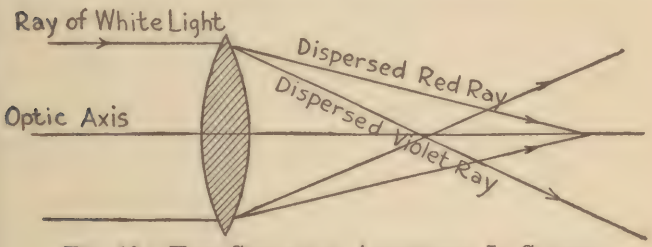


FIG. 10.—HOW CHROMATIC ABERRATION IS CAUSED

light. These different colors are known as the colors of the spectrum; named in order they are violet, indigo, blue, green, yellow, orange and red.

In passing through any kind of a lens it so happens that the two extremes of the spectrum —violet and red—are refracted unequally and therefore are bent in different directions. This causes the ray of white light to be split up, or *dispersed,* into its component colors (since the intermediate colors are also refracted un-

equally), and in this way the image is again thrown out of focus and made indistinct.

In this case, though, there is an additional evil, for the blurred edges of the image take on all of the colors of the spectrum. Figure 10 shows how chromatic aberration is caused by a double convex lens. It is clear that the very purpose of the microscope would be defeated if some means had not been found to correct the spherical and chromatic aberration of the lenses. The corrective methods employed will be explained in the following chapter.

CHAPTER III

HOW THE COMPOUND MICROSCOPE WORKS

You have seen how a magnifier is made and how it works; the next step is to take up the compound microscope, find how it is constructed, learn what its optical properties are, and especially about the action of light which, in passing through it, forms the highly enlarged image of the object under examination.

From the last chapter you learned that ordinary convex lenses have two serious inherent defects which, if they could not be counteracted, would prevent them from being used for high power microscopic work; these are spherical and chromatic aberration. Now, before going into the action of the compound microscope, you should know how these defects are remedied so that the instrument will give a clear and sharp definition.

How Spherical Aberration Is Corrected.—Spherical aberration, as you know, is caused entirely by the shape of the lens, and, further, as was shown in Chapter II, it is least in a double concave lens. With a demand for lenses

in which this defect is obviated, or at least reduced to the smallest possible amount, lens-makers set to work to overcome it. Finally it was discovered that a lens could be made in which the amount of spherical aberration was reduced to an almost negligible quantity.

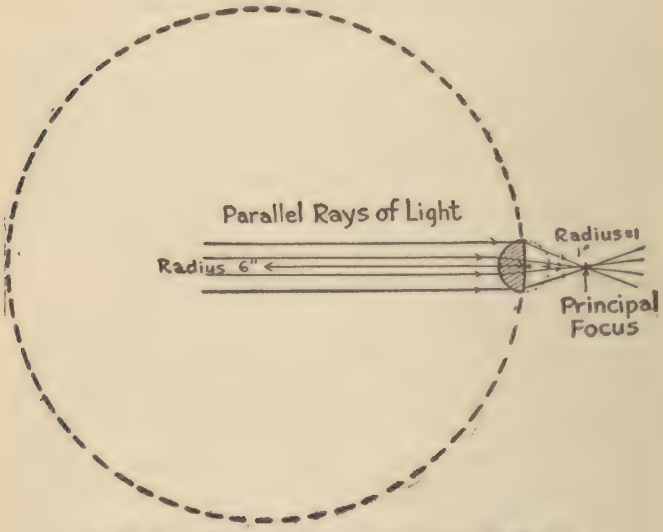


FIG. 11.—HOW AN APLANATIC LENS IS MADE

This was done by grinding the lens so that the curvature of the two surfaces, or faces, as they are called, is unequal, one being considerably more convex than the other. The point at which spherical observation is reduced to a minimum occurs when the radii[1] of curvature

[1] Plural of radius.

are in the proportion, or ratio, of six to one; this is clearly shown in Figure 11. It must be borne in mind, however, that this holds good only when the *more curved surface* is nearest the object to be examined, for when the other side is turned toward it the spherical aberration then nearly reaches a maximum. A lens corrected for spherical aberration in this fashion is known as an *aplanatic lens.*

How Chromatic Aberration Is Corrected.—The natural dispersion, or splitting up, of white light by a lens, and the unequal bending, or refraction, of its component colors,[2] is due to two things: (1) the kind, or nature, of the glass of which the lens is made; and (2) the refracting angle of the lens.

For the purpose of making this clear let us again take the case of white light passing through a prism, since the action of the prism on light passing through it is more apparent than that of a lens, although the principle is identical. By referring to *B* in Figure 6 you will note that the angle *B-A-C* is known as the *refracting angle.* This angle determines the amount, or degree, to which the rays of light passing through the prism will be reflected.

If, now, two prisms are made of the same kind of glass and have the same refracting angle, in

[2] These are found by the difference in the wave lengths that make up the ray.

other words, if two prisms that are exactly alike are placed side by side, one being set in an inverted position, the dispersive power of the first prism will be exactly counteracted, or neutralized, by the second prism, because that of the second prism is equal to and opposite that of the first one. Figure 12 shows precisely how this is done.

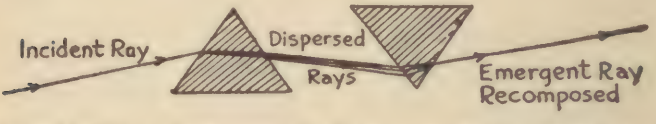


FIG. 12.—HOW DISPERSION IS NEUTRALIZED BY A SYSTEM OF PRISMS

On the other hand, you will see from Figure 12 that not only is the dispersive action of the first prism reversed but that its refractive power is also neutralized by the second prism, since the ray of light which finally emerges from it is parallel to the ray of light that enters the first prism. For this reason in such a system of prisms, although the evil is done away with, refraction—that property of prisms and lenses which makes the formation of images possible—is also done away with, or, rather, its effect is neutralized. This makes this scheme of itself of no practical use in the construction of instruments.

Fortunately for the optical inventor his resources were not entirely exhausted when he

reached this point for he had learned that prisms made of different kinds of glass have different dispersive powers. In particular he had learned that a prism composed of a certain kind of glass known as *flint glass* has twice the dispersive power of one made of the kind known as *crown glass*, while their refractive powers are practically the same.

Further it was known that a prism having a refracting angle of given size would have twice the refractive power of a prism having one-half as large a refracting angle, and that if the latter were made of a glass having twice the dispersive power of the first, the dispersive power of both prisms would be the same, since the power of dispersion varies with the angle of refraction. With these facts to work upon the solution of the problem soon resolved itself down to the following method:

A system of two prisms is arranged as shown in Figure 12. The first prism, however, is made of crown glass which has only half the dispersive power of the second prism which is made of flint glass. Further, the first prism is given a refracting angle twice as great as that of the second. As a result of this combination, which acts in accordance with the principles outlined above, dispersion is entirely destroyed because that of the second prism is equal and opposite in nature to that of the first. The second

prism, however, having a smaller refracting angle will not neutralize all of the refraction set up by the first prism and, consequently, it will be possible for an image to be formed.

What the Achromatic Lense Is.—Now, since the same principles which apply to prisms also apply equally to lenses, a lens may be corrected for chromatic aberration in the same manner as described for the prism and such a lens is

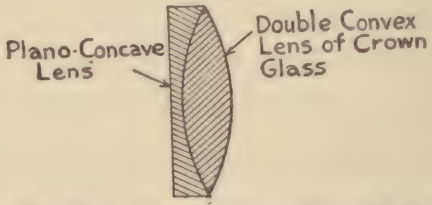


FIG. 13.—HOW AN ACHROMATIC LENS IS MADE

known as an achromatic lens. The correction is accomplished like this: a double convex lens of crown glass is fitted into a plano-concave lens of flint glass and their opposite curvatures are adjusted so that the flint glass compensates for all of the dispersion caused by the crown glass lens, but at the same time it neutralizes only half of the refraction caused by the crown glass.

It should be noted here that lenses made of flint and crown glass as described above are not only *achromatic* but also tend to be *aplanatic,* that is, they tend to decrease the amount

of spherical aberration as well as to eliminate chromatic aberration. A cross section of the achromatic lens is pictured in Figure 13. Having seen how the inherent defects of lenses are corrected so that they can be used for high power microscopic work you are now ready to take up the compound microscope and learn how it produces such a tremendous magnification of an object which may be invisible to the eye even when this is aided by ordinary lenses.

The Lenses of the Compound Microscope.—In its simplest form the compound microscope consists of (1) an *objective lens,* or *objective,* as it is called for short; this is a double convex lens, and is called an objective because through it the rays of light from the object first pass; (2) this objective is mounted in a tube, the purpose of which is to exclude from the eye all rays of light except those passing through the objective from the object; (3) in the other end of this tube is mounted another and shorter tube which has fixed in it (4) the *ocular,* or *eyepiece,* which can be moved toward or away from the objective, all of which is shown in *A* in Figure 14.

It is through the ocular that the magnified image formed by the objective is viewed by your eye and it is by the former that the image is still more highly magnified. In order that the object may be made sufficiently luminous so that

it can be clearly and distinctly seen, there is (5) a mirror placed under it, or a mirror or

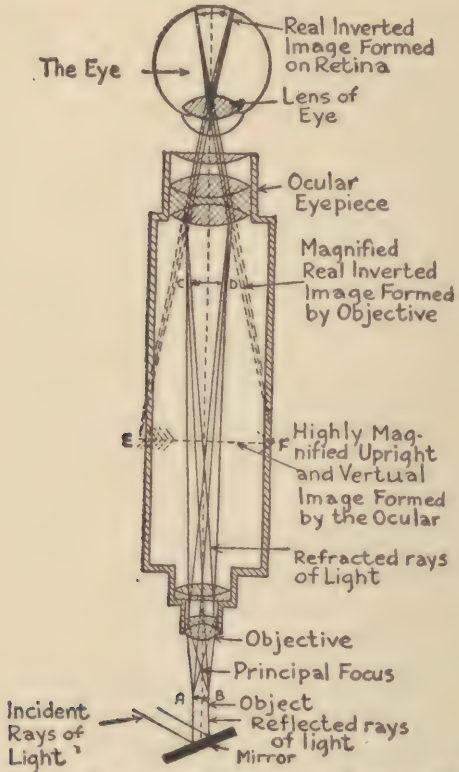


FIG. 14.—HOW A COMPOUND MICROSCOPE FORMS A MAGNIFIED IMAGE

a lense above it, which throws the rays from some source of light upon it. In the first case the light is reflected by the mirror and passes through or to the object to be exam-

ined, and in the latter case the light is concentrated upon and is reflected by the object.

So that you can clearly understand the action of the rays of light after they are reflected from the object and refracted by the lenses of the microscope take a look at *B* in Figure 14, which shows diagrammatically how the magnified image is formed by a modern compound microscope. You will note that the lenses shown are achromatic, but these are shown only to lend the aspect of realism to the diagram, their action being the same as that of the ordinary double convex lens previously shown and described.

How the Microscope Forms an Image.—In the first place rays from the mirror through the object *A-B* and pass up and through the objective. By tracing the path of these rays of light, which are refracted on passing through the objective, you will find that a *real inverted image C–D* is formed near the ocular, or eyepiece; that is to say, if you placed a screen at this point the inverted image would be thrown upon it. This image is considerably magnified but not nearly enough for the purposes of high power microscopic work.

You will observe that this image is *inside* the principal focus of the ocular lens, so that, as I explained in Chapter II, a greatly magnified *upright* and *virtual* image will be formed by the

action of the rays from the image of the objective in passing through the ocular as at *E–F*. You can easily prove this by tracing the divergent rays which emerge from the ocular backward in the same manner as you did at *C* in Figure 8.

At the same time, when you look into the eyepiece, the divergent rays emerging from the ocular pass through the lens of the eye, and since these rays emanate from a source that is outside the principal focus of the latter, the divergent rays are once more refracted and brought to a focus when another *real inverted image* is formed on the retina of the eye. The image which the brain senses, however, is the virtual image *E-F*, since the rays of light which form the image on the retina of the eye have as their apparent source the image *E-F*.

It is in this way that you see an image enlarged a hundred, a thousand, or even a million times, and, while it does not usually make any particular difference, you should bear in mind when looking through a microscope that the image you see is inverted, or upside down and also reversed, or wrong end to. This fact need cause you no concern, though, for knowing it you will soon accustom yourself to visualizing them as if they were really right side up, and right side to.

What Changing the Adjustment Does.—It must, of course, be clear that an endless variety of magnifications can be had with the same lenses in the microscope by simply changing the relative position of one to the other and the relative position to the object itself. For instance, if the eyepiece is drawn away from the objective, while the objective is moved toward the object, the image will be formed at a greater distance from the objective than before, and as a consequence it will be even more greatly enlarged.

If, on the other hand, the operation is reversed, that is, the eyepiece is brought closer to the objective, and this is farther removed from the object, then the image will be formed much nearer the objective than before, when it will, naturally, be considerably diminished in size. From this it is evident, in view of extreme magnification of the image formed by the objective by the lenses of the eyepiece, that the adjustment of the lenses in their relation one to the other and to the object must be exceedingly small in order to obtain a sharp image.

This being true, the microscope must be built with a good deal of accuracy, and a means for adjusting it must be provided which will permit the lenses to be moved the smallest fraction of an inch at a time. In the following chapter I shall explain the construction of the mechan-

ism employed in both the cheaper and the more expensive types of microscopes. It is necessary, however, before going into the details of construction, to explain two other factors which affect the action of the microscope; these are (1) the aberration caused by different media[3] and (2) the shifting effect caused by the cover glass.

Aberration Caused by Different Media.—First you must know that not only glass refracts light, but also air, water, oil and all other transparent substances, or *media* as they are called, that is, substances through which light readily passes. In mounting microscopic objects a thin glass, called a *cover glass,* is often used to preserve the *mount,* as the object is called, and at the same time to protect the objective.

The cover glass is placed over the object so that the path of the light waves from the object lies through it as well as through the air between it and the objective of the microscope. This refracts the rays of light in two different ways, and this in turn reduces the number of light waves passing from the object which can be received by the objective.

Shifting Effect Produced by the Cover Glass.—Now, if you will take a look at Figure 15 you will see at a glance just how this appar-

[3] Plural of medium.

ent shifting of the object, or *aberration,* is brought about. Not only prisms and lenses cause the refraction of rays of light which pass through them, but a piece of plain glass has the same property, though, naturally, to a very much less extent. Hence, as shown in Figure 15, any two rays of light coming from a point on the object which is being examined such as *O–A* and *O–B* upon passing through the cover glass are refracted.

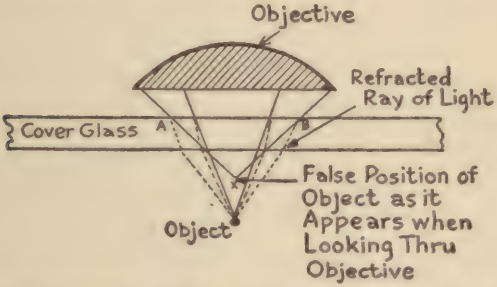


FIG. 15.—SHIFTING EFFECT CAUSED BY A COVER GLASS

When they leave the cover glass, the air between the glass and the objective tends to refract these rays still more. The result of this refraction by the cover glass and the air, as far as the objective is concerned, is such that the rays might just as well have had their source at *X* instead of *O,* and when you are looking through the microscope this is to all intents and purposes the case. In like manner the rays from any other point of the object will be apparently

shifted and so change the whole position of the object when viewed through the microscope.

This aberration of the cover glass is taken into account by the makers of the objective of the microscope so that the proper correction is obtained.

About the Immersion Objective.—High grade microscopes are usually fitted with what is termed an *immersion objective,* and, as you may have occasion to use one some time, I will tell you about it. You have seen that air also refracts the rays of light which pass into it after leaving the cover glass, and this optical property of the air likewise has an important effect on the action of the microscope.

In the first place it is necessary, where a high magnification is needed, that the objective be as small and of as great curvature as possible; and with such a lens, after all the various refractions to which the rays of light from the objects are subjected before reaching it, it is very hard to get enough light through to see it clearly. Moreover, it often happens that the rays coming from the point of the object toward the outside edges of a lens are highly important when you are examining the finer structures of it. Should these rays be so refracted that they do not strike the outer edges of the lens, the image formed will not show the minute details of the object.

In ordinary microscopic work the air is the medium used between the cover glass and the objective as pictured at *A* in figure 16, and which clearly shows how the ray *O–B* is refracted by the air after leaving the cover glass. So divergent are these rays that they do not reach the objective at all. To the end that this defect may be corrected, it is evident that some medium other than air, and one having the same

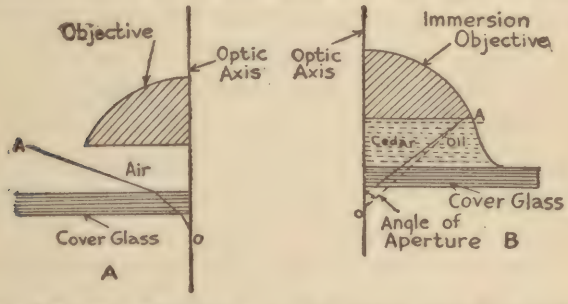


FIG. 16.—THE PRINCIPLE OF THE IMMERSION OBJECTIVE

refractive power as the cover glass, must be used.

At first water was tried as a substitute for air, and, while it gave better results, it did not prove altogether satisfactory. After a great deal of experimenting it was found that *cedar oil*, which has the same *index of refraction* (as the refractive power is called) as glass, gave satisfactory results.

A drop of cedar oil placed between the objective and the cover glass will make the rays,

which would otherwise be lost in air, pass up to and through the objective as shown at *B* in Figure 16. An objective so constructed that oil can be used in this way is called an *immersion lens;* this is one of the greatest single steps ever taken in the improvement of the compound microscope.

What the Numerical Aperture Is.—In microscopy you will often come across the term *numerical aperture* in connection with objectives, and you should know what it means. The angle formed with the optical axis at which the most divergent rays of light pass from an object through the objective is known as the *angular aperture* of a lens. It is shown at *B* in Figure 16.

This angle, very naturally, increases as the curvature of the lens increases. Likewise it will be greater when an immersion substance, such as cedar oil is used. From this you will see that the numerical aperture of a lens has a direct relation to the angle of aperture and the refractive power of the oil, or other medium, in front of the lens. It is obvious, too, that the greater the numerical aperture the more effective will your objective be—and consequently your microscope—in viewing an object.

CHAPTER IV

HOW THE COMPOUND MICROSCOPE IS MADE

Any kind of a compound microscope, be it a cheap, or an expensive, one, is an instrument of precision. Outwardly, and to all intents, a compound microscope seems rugged enough, but, actually, and of necessity, it is a delicate instrument, consequently (1) considerable thought must be given to selecting one that will properly serve the purpose for which you want to use it; and (2) much care and attention must be exercised in using it.

Buying a Microscope.—Like other instruments, machines and tools you will find different kinds of microscopes on the market, ranging from a little one that has a magnifying power of 100 times and which costs $7 or $8, to a higher grade instrument that has a magnifying power of 1,000,000 times or more and which costs several hundred dollars. A cheap microscope will serve your needs as a beginner and for all ordinary household purposes, but if you expect to go very deep into microscopic

work, I would advise you to spend $25 or $30 for an instrument.

In any event the price you pay for a microscope will, no doubt, be determined very largely by your pocketbook. Cheap microscopes can be bought of dealers in optical goods generally. If there is none in your town you can get them from any of the well-known dealers in optical goods in New York, Boston, Buffalo, or Rochester.

Your first microscope, like your first motor car, will be subjected to various kinds of abuse and so, for this reason if for no other, you should begin with a medium-priced one. Before advising you further as to what to look for when buying a microscope I will tell you something about the construction of the instrument in general, then you will be better able to go about the selection of one intelligently.

Parts of a Compound Microscope.—It is a good scheme first to learn the names of the different parts of the microscope and their uses. A recent type of microscope with its parts named is shown in Figure 17, and for convenience let us start at the bottom and work up, taking the construction and purpose of each part in turn.

As you will see from the picture a good microscope has quite a number of parts, the chief ones being (1) the *base,* (2) the *pillar,* (3) the

joint, (4) the *mirror,* (5) the *substage,* (6) the *stage,* (7) the *arm,* (8) the *coarse adjustment,* (9) the *fine adjustment,* (10) the *objective,* (11) the *body tube,* (12) the *drawtube,* and (13) the *ocular* or *eyepiece.*

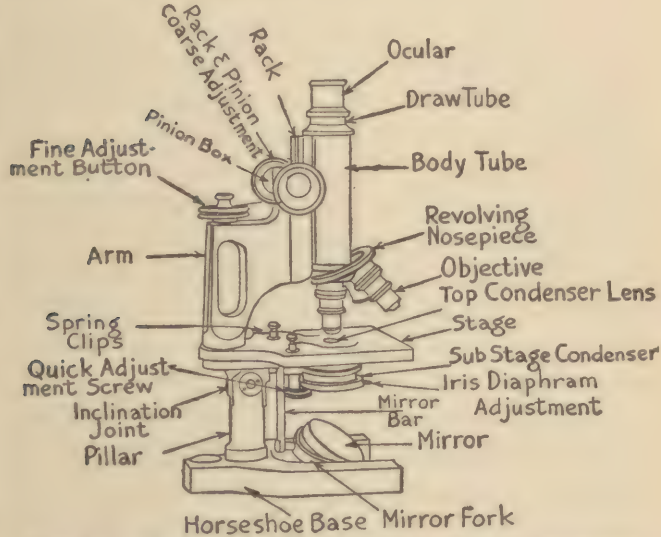


FIG. 17.—NAMES OF THE PARTS OF A GOOD MICROSCOPE

The Base.—The most common form of base used in American makes of microscope is the horseshoe type, which, as its name indicates, is made somewhat in the shape of a horseshoe. The base, whatever its shape may be, should give the microscope absolute steadiness in whatever position it is being used.

Unless the base has this property, which de-

pends on (*a*) the weight of it, and (*b*) the way in which the other parts are attached, that is, whether it is well balanced or not, however well made it is in other respects, it will never give you the satisfaction that you have the right to expect from it.

The Pillar and Joint.—This is an upright solid standard fixed firmly to the base and projecting vertically from it. Its upper end is provided with an *inclination joint,* into which the lower part of the arm is fitted, the pillar being slotted to receive the keyed end of the arm. By means of this joint, the arm, and, consequently, the body of the instrument can be tilted or inclined to any angle between the vertical and the horizontal.

The joint is made just loose enough so that the arm can easily be tilted to any angle you wish, but will remain in the position you give it unless you again bring pressure to bear on it. This result is secured by means of a pin which runs through the pillar and the key of the arm. The pin is usually slightly conical in shape and is threaded on both ends with nuts screwed on them.

The necessary friction to make this joint work properly is produced by drawing the conical pin into the bearing; to do this you tighten one of the nuts, which should have either a slot cut in its face so that a screw driver can be used

on it, or two small holes so that a *spanner* can be used on it.

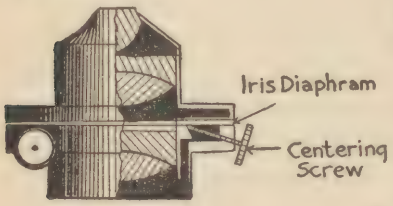
The Mirror Bar.—To the front of the key is fitted a *mirror bar* which can be moved sidewise. Projecting from the lower end of this arm and at right angles to it is pivoted a *mirror fork;* this carries a swinging mirror between its prongs. This arrangement of pivots permits the mirror to be turned in all directions and, as with the inclination joint, these pivots are just loose enough to allow the mirror to be swung easily in any direction and at the same time to hold it in place when once it is adjusted. Usually the mirror has two faces, one plane and the other concave; this makes it possible to focus the light on the object under all conditions.

The Substage Condenser.—This is a device that is fixed to the under side of the stage, in the better grades of microscopes. The *condenser* is made up of achromatic lenses, usually two, mounted in a shallow tube. The purpose of the condenser is to throw a sharp and perfectly achromatic light on to the object, which in this case must be transparent.

To get the best results when using a condenser the latter must be made almost as carefully as the objective itself. A cross section through an *Abbe* achromatic condenser[1] is

[1] A further improvement in the condenser is a quick-acting adjusting screw; when this is turned up as far as possible

shown at *A* in Figure 18; from this you can see how the lenses are arranged. While the cheaper microscopes are not provided with a condenser an important feature of all good microscopes is the iris diaphragm which is pictured at *B* in Figure 18.



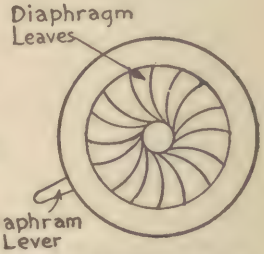


FIG. 18A.—ACHROMATIC SUBSTAGE CONDENSER WITH HALF CUTAWAY TO SHOW LENS COMBINATIONS

FIG. 18B.—THE IRIS DIAPHRAGM

Where the microscope is fitted with a condenser the diaphragm is placed between the achromatic lenses as shown at *A*. The iris diaphragm is so named because, like the iris of the eye, or pupil, it is a mechanism by means of which the amount of light passing through it can be regulated. In the human eye this function is performed automatically, while in the microscope it is done by changing the position of a small lever that projects from the side of it.

The diaphragm itself consists of an ingenious

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the upper lens of the condenser is brought into the stage so that it can be used in immersion contact with the slide in the same way and for the same reason that I have described for immersion objectives.

arrangement of small overlapping plates or leaves, and as the lever is moved one way or the other they close and give a large central aperture, or spread out and give a small aperture for the light to pass through. It is made on exactly the same principle as the shutter of a camera.

The Stage.—This is a small platform that is rigidly fixed to the lower part of the arm and upon which the object is placed when it is to be examined through the microscope. It is formed of a slab of metal or hard fabricated material with a small hole in its center so that the light reflected by the mirror can be projected up and through the object on the slide.

The stage is fitted with a pair of spring clips to hold the slide that contains the microscopic object in position. A convenient form of stage, but which comes only on the higher grade instruments, is the revolving type. It is so made that the stage and object fixed to it may be rotated so that it can be viewed from all angles. A revolving stage, however, is not a necessary adjunct to good work. Still more expensive instruments are provided with a mechanical stage in which the slide can be moved by turning a thumb screw; in this way any part of the object can be brought quickly and accurately into the field of the objective.

The Arm.—The makers of microscopes are

constantly improving them even as to design. The slotted arm pictured in Figure 17 is to my way of thinking easier to handle than the later type with the long curved arm shown in figure 18, but this may be because I am more accustomed to the use of the former. The curved arm, however, has an advantage in that it is easier to manipulate the slide on the stage because the latter is left more open. Either design will fully satisfy your needs.

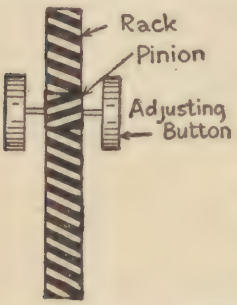

FIG. 19A.—THE COARSE ADJUSTMENT

The Coarse Adjustment.—This adjustment, the purpose of which is to enable you to focus rapidly the object on the stand, is secured to the upper part of the arm. The mechanism that is in general use is known as the *rack* and *pinion adjustment.* It consists of a rack, that is, a strip of metal with teeth cut in it, fixed to the body tube of the microscope, and a pinion, which is a small-toothed wheel, mounted, on the arm. The teeth of the pinion mesh with the teeth of the rack, and when the coarse adjustment screws are turned the pinion causes the rack to move up or down according to the direction the screws are turned as shown at *A* in Figure 19.

The rack is protected by sliding in a groove

in the arm which prevents dust and dirt from getting into the teeth. If you should ever buy a used microscope see that the rack and pinion work smoothly; you should also observe whether the rack is greased, as this is sometimes done to cover up the defect of well-worn teeth. It is easy to tell by the *feel* of the milled

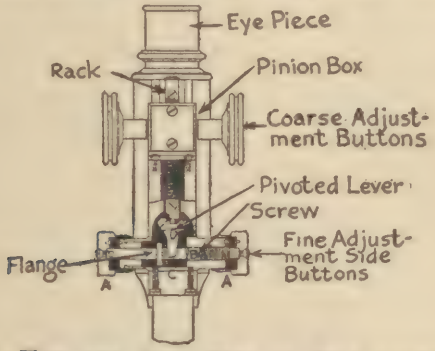

FIG. 19B.—HOW THE BEST TYPE OF FINE ADJUSTMENT IS CONSTRUCTED

adjusting screws if the rack and pinion movement is in good working condition.

The Fine Adjustment.—Of even greater importance than the coarse adjustment is the fine adjustment, for it is with this latter mechanism that you get the final focus. Without regard to the merits of the other parts of the instrument the fine adjustment must work smoothly and accurately, hence the mechanism which produces this result must be delicate and of limited range.

There are two distinct kinds of fine adjustments in use; in the first *one* micrometer head is secured to the top of the arm, and in the second *two* micrometer heads are secured to the opposite sides of the arm. This latter arrangement is the one that is most commonly used; its construction is shown at *B* in Figure 19. It is very durable, since it is built with the fewest number of parts possible and has only two bearing surfaces.

The side buttons *A* are fixed to the screw *B* which carries a heavy flange *C*. The screw has two bearings; the one on the right hand has a fine thread which engages with the micrometer threads of the screw, and the one on the left hand is plain, since the screw is not threaded at this end. When either of the side buttons are turned the screw travels into or out of its bearing, and the heavy flange *C* works against the pivoted lever *D* so that when the flange is carried forward the lever is raised, thus carrying the body tube with it, or lowering it if the movement is reversed. One revolution of the focusing button moves the tube two *millimeters* up or down.

The Objectives.—A microscope of fair power should have at least two *dry objectives*—that is, objectives that work with air between them and the object. One of these should be of low power and the other of high power. An *oil im-*

mersion objective is also handy to have as part of the equipment, although this is not necessary for elementary work.

Objectives of the first kind are *fixed,* that is, the lenses are secured in the tube so that they cannot be changed. *Adjustable* objectives, in which the position of the lenses can be changed in order to compensate for the shifting of the object and variations in the cover glass, are also made, but they are useful to skilled microscopist only, as he only would thoroughly understand them. Those of the fixed type will serve your every need.

Where two or three objectives are used, as in the better grade of microscopes, they are secured to a revolving element called a *nose piece.* The rotating part of the nose piece carries the objectives and the fixed part of it is attached to the lower part of the body tube. This arrangement is so made that one can change from one objective to another by simply turning the nose piece around, when the objective you want to use will be under the body tube and in a line with the eyepiece.

These nose pieces are made so that they *lock* when the objective is in the right position for use. They are also made *parfocal,* that is, they are so designed and constructed that if one of the objectives has been focused on an object and another one of higher or lower power is swung

into its place, it will also be in fairly good focus.

Moreover, the objectives are pretty closely centered, so that a point in the center of the field of one of them will be in the center of the field of the other, when it is swung into place. Of course the objectives are aplanatic and achromatic as described in Chapter III, and they are corrected for a tube of standard length, which is 160 millimeters, and for aberration caused by a cover glass that has a thickness of .18 millimeter, which is the usual thickness.

The Body Tube.—This is the main tube, and while it acts as a support for the lenses, it carries no lenses itself. The purpose of it is to hold the drawtube and to provide a convenient means of protection for the former as well as a rigid mounting in which it can be moved up and down. The body tube further carries the rack fixed to it for the coarse adjustment.

The Drawtube.—In the upper end, and moving in a cloth-lined sleeve, is carried the *drawtube;* this in turn holds the ocular or eyepiece. In the better makes of microscopes the drawtube is often graduated to show what the tube length is, that is the distance from the objective to the ocular as it is drawn out or pushed into the body tube. The purpose of the drawtube is to vary the distance between the ocular or

the eyepiece, the objective thus increasing or decreasing the magnification of the object.

The Ocular or Eyepiece.—This is carried by the upper end of the drawtube and consists of a *doublet,* that is, two lenses mounted in a short tube. Oculars are made that give different magnifications and are, therefore, either lettered or numbered to show what the magnification is.

A good microscope usually has two oculars, one of which gives a magnification of, say, *5* times, hence the ocular is marked *5X; the* other gives a magnification of *10* times, or *10X.* All up-to-date oculars made by American manufacturers are marked in this way, and this mark represents the increase in magnification that the ocular gives to the real inverted image which is formed by the objective.

Thus if the objective has a magnifying power of *10X,* that is, if the image formed by it is *10* times larger than the object itself, when an ocular marked *10X* is used, it will produce a virtual image which is ten times as large as the image produced by the objective, or *100* times larger than the object itself.

You can also determine roughly whether an objective, or an ocular, is of high or low power by its length. A long ocular is usually of low power, while a long objective is, as a rule, of high power; and the other way about is also

true for oculars and objectives which are short. The relative sizes of the lenses in oculars or objectives also determine, in a measure, their magnification, for large lenses in the first usually show high power, and, in the second, low power.

CHAPTER V

THE RIGHT WAY TO USE A MICROSCOPE

From what I have told you in the foregoing chapter you will see that the microscope is an instrument that needs care and must be handled with consideration, so now a few simple directions as to how to use it are in order.

Getting Your Microscope Ready for Work.—If you have just bought a microscope you will find it packed in a neatly made box or case, and this you should keep. When you are not using the instrument, you should always keep it in the box, as this will prevent dust and dirt from getting on and in it. If you have a high grade instrument, you should procure a bell jar to set over it when it is not in use, as this makes it easy to get at and at the same time it requires less handling.

On opening the box or case, you will find the microscope all assembled and ready for use, with its objectives in place and the ocular in the drawtube. In taking the instrument from the box the safest way is to pick it up by the base with one hand and by the arm with the other

hand. In removing it be very careful not to strike the adjustments or the nose piece, if there are any. When you have it out of the box you can hold it by the arm, but if you intend to carry it any distance always use the box.

How to Take Out the Objective.—The next step is to take out the objective and ocular and clean them. To remove the objective from a cheap microscope, you need only to unscrew it

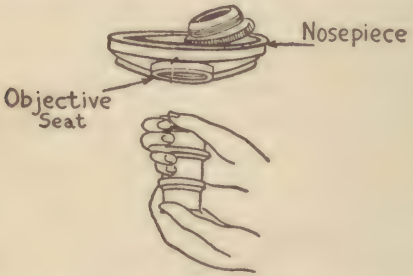

FIG. 20.—HOW TO REMOVE AN OBJECTIVE

from the tube, but to remove the objective from the nose piece of a high grade instrument, you must go about it a little differently.

The first thing to do when you want to take out an objective is to raise the tube of the microscope by means of the coarse adjustment until the lower end of the objective is well away from the stage; then you can easily grip it with your fingers. The nose piece should be turned around until the objective which you want to

take out sets at its outer edge and to the front of the microscope.

Now grasp the objective lightly at its lower end with the forefinger and thumb of your left hand, and take hold of the milled ring near the lower end of the objective with your right hand as shown in Figure 20. You can then unscrew it without danger of dropping it.

How to Put the Objective Back.—When putting the objective back in the nose piece use both hands as before. In doing this, however, even greater care must be used than when taking it off, and you must see that the threads of the objective mounting are started evenly with the threads of the nose piece. Should you fail to get the threads to mesh evenly, you will not only break them but the objective will be thrown out of line.

It is not at all difficult to screw the objective in right, but as the threads are very fine and the position a little hard to work in, they will not always start in even. If the threads should become damaged by careless insertion of the objective you will have to get both the mounting of the objective and the nose piece rethreaded by some optical instrument maker and this will take time though it may not cost you very much.

How to Take Out the Ocular.—When you want to take out an ocular grip it by the milled ring next to the eyelens and hold the micro-

scope either by the coarse adjustment or by the tube. Now, if you give the ocular a gentle but firm rotary and upward motion it will leave the instrument easily. As with all lenses be careful not to drop it.

How to Put the Ocular Back.—To put back the ocular you simply reverse the operation described above for taking it out; you should see however, that the objective is raised a goodly distance from the stage, especially if a slide is in place. If this is not done and your ocular fits rather snugly into the drawtube, you are liable, in pressing it down, to push the objective down also, in which case it will come into contact with the slide with undue force.

How to Clean the Optical Parts.—After you have taken the oculars and objectives out, lay them on a soft cloth to prevent them from becoming scratched. It is evident that, unless the lenses are absolutely clean, no matter how carefully you adjust the instrument you will not be able to get anything like good results.

Should you find that the lenses are dirty, wipe them gently with a piece of *Japanese lens paper,* which you can get from any optical supply house. You can use a piece of very soft linen instead of the paper, but it must be perfectly clean. Never use chamois skin, for you cannot really clean a lens with it because it contains natural oils that are apt to (1) form a

film on the surface of the lens, and (2) cause dust and dirt to stick to the film, which, on cleaning the lens again, will scratch it.

Always rub a lens very gently when cleaning it, for, should there be any grit on it, there is always danger of scratching it. Further, you should never touch the surface of a lens with your bare fingers as they contain natural oils. Moreover, there is apt to be some slight perspiration on them, and when this gets on the lens it is very hard to get off. When picking up a lens that you have taken out of its mounting, you should either pick it up by its edges as shown in figure 21, or with a piece of fine linen cloth.

FIG. 21.—THE PROPER WAY TO HANDLE A LENS

How to Clean an Objective.—Sometimes the front lens of an objective, that is, the lens that is exposed, becomes so soiled that you cannot get it clear merely by wiping it. In this case try breathing on it and then wiping it. Should this fail to remove the film of dirt moisten your Japanese paper with a few drops of *xylol* or *chloroform;* this will take it off. Be sure to wipe the lense perfectly dry after you use these cleaning agents.

Then, too, it will be found that dust often settles on the back lens of an objective even

though the eyepiece has been left in the tube, as it always should be. If dust has settled on the back lens never try to take the objective apart, for this is a job that belongs to the instrument maker. Use a small *camel's hair brush* to remove this dust; usually this is all the back lens ever needs.

After using an immersion objective you should clean it immediately; this you can do by gently wiping it dry with a piece of lens paper. If the cedar oil has been allowed to dry on the lens you can get it off either with xylol or chloroform. The better way is to clean your immersion objective as soon as you have used it.

How to Clean the Ocular.—The same methods of cleaning the oculars are used as those described for the cleaning objectives. A grayish film is sometimes formed on the inner surfaces of the lenses that make up the ocular. When this happens, remove the lenses from the tube as follows: both the upper and lower ends of the tube have a milled ring which holds the lenses, and these screw into the tube. By unscrewing these from the eyepiece you can get at the inside surfaces to clean them. After taking out the lenses, you will find, about one third of the distance from the lower end of the ocular tube, a metal ring, known as the *ocular diaphragm;* you should clean this also.

How to Clean the Condenser and Mirror.—If your microscope has a condenser you should clean it with the same care and in the same way that I have described for the objective and the eyepiece, since the best results can be obtained only when the condenser is perfectly clean. The mirror also should be well cleaned. When you have all of the parts thoroughly cleaned you are ready to give your microscope a tryout but not before.

Choosing a Place to Work.—The choice of a place to do your microscopic work is of great importance. The first essential is good light, the next plenty of room and at the same time comfort. Microscopic work is absorbing and once you have started in to examine objects you will not want anything to interfere. Therefore, be sure that everything is as it should be before you start.

Having found such a place set your microscope on the table near the edge, as shown in Figure 22; the table must be neither too high nor the chair too low for you to look into the instrument without straining yourself to do it. If you are working with fresh mounts or fluids you will have to keep the stage parallel with the table top, that is, in a horizontal position.

If, however, you are working with the object mounted on a glass slide you can tilt the microscope by means of the inclination joint to any

position where you can see to the best advantage. It is considered the best practice, though, always to use the instrument in a vertical position as shown in Figure 22.

FIG. 22.—THE CORRECT WAY TO USE A MICROSCOPE

Getting the Right Light on Your Work.—*Using Daylight.*—As I have already pointed out, next to the instrument itself the chief thing in using the microscope is to get the best light on the object under examination that you can If you pay attention to this all-important factor, and also learn to use your microscope with both eyes open and to use either eye at will, no

reasonable amount of work will injure your eyesight.

But you should never work in the direct sunlight, for too bright a light is as bad for the eyes as too little; instead, choose a place that is well lighted from the reflection of the sky alone. Further, there should be no object directly between you and the source of light, such as the moving branches of trees or shrubbery, or the wire netting on the window, as these all prove annoying. So much for the use of natural light, which is far better than artificial light for your eyes if you can get it.

Using Artificial Light.—Should you have to use artificial light, it is absolutely necessary that it be steady, that is, the light must be equal in intensity and quality, and must not flicker. A good light of this kind is that given by a *tungsten filament* electric lamp which has a ground glass bulb. Where an electric light is not available a *Welsbach* gas mantle light, or even an ordinary gaslight, can be used; if the latter is used, the narrow edge of the flame instead of the broad side should be set toward the mirror.

You will remember that a light which is small and near gives off divergent rays, and, therefore, when using an artificial light, place a condensing lens between it and the mirror of the

microscope, so that the divergent rays will be brought to a focus.

Further, to soften the light, you should place a piece of blue glass between the light and the mirror, or better, use a glass globe filled with a solution of ammonium copper sulphate; this will act also as a condenser. The globe should be mounted in a frame or shade so that all the other rays from the light, except those that go through it, will be cut off from the microscope. Finally, you will find it to your advantage, when using an artificial light, to wear an eye shade that will shut out all outside rays, as it is these that are the chief cause of eyestrain.

How to Focus Your Microscope.—Put a low power objective and ocular in place, and then insert a slide with a transparent object on it that you want to examine under the spring clips on the stage. Now adjust the mirror so that when you look through the ocular the field of the objective appears to be illuminated evenly and brightly. You should then bring the objective down until it nearly touches the object, or cover glass, if the object is permanently mounted, and in doing this you should use the coarse adjustment. This is known as *focusing down;* while doing this you should watch the movement of the objective from the side to see that you do not run into the object.

Next place your eye close to the eyepiece, and

with the coarse adjustment bring the objective away from the object, or *focus up,* as it is called. You will soon reach a point where you will plainly see the object. This done you are ready to use the fine adjustment which will give you the sharpest focus possible and, hence, the best definition.

You can safely *focus up* with the fine adjustment, but you should be very careful in *focusing down,* because the movement of the objective is so very small for the distance you turn the adjusting button that you are very apt to run the objective on to the object. As you are focusing with the coarse adjustment, it is a good plan to keep the object moving about a little on the stage, as it is easier to find it, that is, to get it in the center of the field, when it is moving than when it is still.

At first you may become confused by the fact that the image as seen by your eye is reversed, and also by the act that the microscope magnifies the movement as well, thus making it appear as if you were moving it faster than you really are and *in the opposite direction.* You will need only a very little practice to be able to adjust the object to a nicety.

The right way to examine an object is to use a low power objective and ocular first before trying a high power, because a low power shows more of the object and thus gives you a better

idea of its general appearance. When you want to examine some particularly interesting part of an object you can switch over to a high power objective and ocular, as this will bring out all the finer details. In the next chapter I shall tell you more about focusing, but the above hints are all you need for your first experiments with the microscope.

How to Care for the Other Parts.—In the beginning of this chapter I told you how to keep the optical parts of your instrument in good condition, and, in closing, I will tell you how to take care of the other, or metal parts. The parts of a microscope that are enameled or lacquered can, as a rule, be readily cleaned by rubbing them down with a soft cloth or a piece of clean chamois skin.

Fingerprints, however, are sometimes hard to remove by this means alone, and when this is the case you can try breathing on the surface first before rubbing. Should this fail, use a cloth *slightly* dampened with water, and, as a last resort, use alcohol, ether, xylol or chloroform. Do not use any of the latter unless the enamel or lacquer is in very bad shape, as they are liable to remove it along with the fingerprints. In any event dry the instrument immediately after cleaning.

How to Care for the Stage.—After a while the stage, especially if it is on a cheap micro-

scope, will turn gray. This is apt to be particularly so after it has become soiled with balsam, immersion oil and other substances which you cannot get off with water. To restore the original black luster of the enamel all you need to do is to rub it with machine oil and then wipe off all the excess oil after the finish has taken on its original polish.

Taking Care of the Coarse Adjustment.—If dirt or other foreign matter should get into the teeth of the rack and pinion, the adjustment will not work smoothly. If this should happen don't force it up and down but clean the teeth with xylol or chloroform, then lubricate with a very little watch oil, or any light machine oil that is free from acids.

Once in a while the bearings may work loose and then the tube will rattle or sway every time you turn the coarse adjustment button. To remedy this, tighten the small screws which are located at the back of the pinion box; this will take up the lost motion. Never try to fill up the teeth of the rack with anything in order to take up the lost motion.

Taking Care of the Fine Adjustment.—If you wish to keep the fine adjustment in working order the one thing you should never do is to take it apart. In some micrometers, especially the older kind, no provision is made for stopping the movement at both ends of the range of

the screw; if your instrument is of this kind, and you are not careful you are as likely as not to run the threads out of their bearing.

Should the screw become thus removed from its bearing it must be replaced with a deal of pains, for the threads are so fine that it is just as easy to start the screw back into its bearing so that the threads will *run* as it is to start it properly. If you should be unfortunate enough to make the threads *run*, the only thing to do is to send the instrument back to the maker and have him rethread the screw and its bearing.

Nearly all of the later model microscopes, however, are so constructed that the micrometer screw has a *stop* at either end of its range which prevents it from being run out of its bearing. Whatever you do, never *force* the micrometer head when it fails for any reason to work smoothly.

How to Clean the Substage.—Should the leaves of the iris diaphragm get gummed up, rusted or dirty, they can be cleaned with xylol, after which you should dry them thoroughly and put the minutest amount of watch oil on them, at the same time working the diaphragm lever back and forth to distribute the oil evenly. Sometimes the threads on the quick-acting screw of the condenser adjustment get gummed up; this can also be remedied by taking out the screw and cleaning it with xylol.

Taking Care of the Nose Piece.—The nose piece can be cleaned in the same way as the other metal parts of the instrument. There are, however, four *dont's* which you must heed: (1) don't put oil between the rotating and stationary parts of the nose piece; (2) don't strike or do anything else to bend the position of the nose piece; (3) don't interchange the objectives (that is, do not put the low power objective where the high power objective was in the nose piece, or the other way about); (4) don't *focus down* on the object until you have *focused up* and changed over from a low to a high power objective unless you are sure that your objectives are *parfocal.*

If your objectives are not parfocal and you do not follow these instructions, the high power objective which is longer than the low power objective will strike the object and both may be damaged. By following the advice that I have given you in this chapter, your microscope will serve you well to the end of your days at little or no expense and with pleasure and satisfaction to yourself.

CHAPTER VI

THE LIGHTING OF MICROSCOPIC OBJECTS

I have already pointed out the importance of proper illumination when you are doing microscopic work, and although I have told you in general how to get the right light on the object, there are some particular points which you should know about.

Kinds of Microscopic Objects.—In the first place there are two classes of objects which you will want to examine with your microscope, namely, (1) *transparent objects,* and (2) *opaque objects.* Transparent objects are those through which light can readily pass, and, hence, can be illuminated from a beam of light under them; opaque objects are those through which light will not pass and, consequently, must be illuminated from above.

Objects for the microscope are of both kinds; those that are transparent, or semitransparent are usually formed of thin sections, that is, slices of vegetable or animal matter, while those that are opaque include masses of matter,

such as whole insects, most minerals and all the metals. The kind and extent of the lighting required to get the best results depend upon the nature of the object you want to examine.

How Transparent Objects Are Illuminated.—For the proper illumination of transparent objects there are two means by which the light can be carried from the object to the objective, namely, (1) the *axial,* or *central, light,* and (2) the *oblique light.*

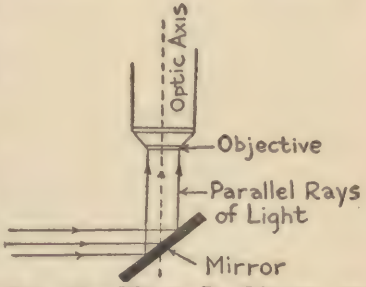

FIG. 23.—WHAT IS MEANT BY CENTRAL OR AXIAL LIGHT

The Axial, or Central, Light.—By the term axial, or central, light is meant rays of light which strike the object and illuminate it in such a way that the rays are all arranged evenly, or *symmetrically,* as it is called, around the optical axis of the objective as shown in Figure 23. In other words, the objective is evenly illuminated.

I have already explained how different sources of light produce parallel or divergent rays according to their size and distance from the object. Thus, when natural light, that is, ordinary daylight, is used, the mirror must be adjusted so that the parallel rays will be reflected upward and through the object evenly from all

sides. If, on the other hand, artificial light is used, then the divergent rays must be reflected from the mirror on to the object, so that the axes of the cones of light formed by the rays will coincide and be parallel with and equally distributed around the optical axis of the objective.

Just how these effects are obtained will be described in detail a little farther on; it is enough to say here that they are brought about by two different ways, depending on whether or not a substage condenser is used in conjunction with the mirror.

How to Illuminate the Object without a Condenser.—While a substage condenser and an iris diaphragm should be a part of every good microscope, still if your instrument is of the less expensive kind, you can get along very nicely without them. This is especially true when working with objects which require the use of low power oculars and objectives; when this is the case you should use the plain side of your mirror to reflect the light from its source on to and through the object.

After you have illuminated the object to the best possible advantage by means of the mirror, as explained in the foregoing chapter, and focused the object as sharply as you can, you are ready to obtain the axial, or central, illumination, and this you do as follows: first take

out the eyepiece from the tube and look down through the latter at the back lens (the top one) of the objective, when you will see a small image of the mirror. Now swing the mirror bar into position so that it is exactly parallel with the body tube of the microcsope. This position is known as the *median line.*

If you have a good microscope of recent make it will be fitted with a *center stop,* and when the mirror bar reaches this point it will be on the *median line* and parallel with the optical axis of the objective. Next adjust the mirror so that its surface will be parallel with the surface of the back lens of the objective, and then make a further adjustment, so that the axes of the cones of light reflected from it will be parallel with the axis of the instrument and evenly distributed around it.

It is absolutely necessary that the mirror be free from all reflections of trees and other extraneous objects which would impair the quality of the illumination. The matter of adjusting the instrument and the mirror in relation to the source of light in order to obtain central illumination is one where a little ingenuity on your part will be of greater service than much direction on my part.

When using artificial light you should be sure that the image of the light can be seen in the center of the mirror, and the larger the image

and the more nearly centered it is, the better will be the results. To get the best illumination with an artificial light the bull's-eye condenser, previously mentioned, should be placed between the source of light and the object, so that the image of the light can be seen clearly in the center of the back lens of the objective.

Further, when using artificial light from an electric bulb, it will be found that a special kind of glass called *daylight glass* will give the best results when placed between the light and the mirror. A sheet of this glass 1¾ inches on the sides can be bought of any dealer in microscopic supplies for about seventy-five cents; it has the property of giving true color values the same as natural daylight to the artificial light when produced by an electric lamp that has a *tungsten* filament, which goes under the trade name of *mazda*. How to make a lantern for using it will be described a little farther on.

Nearly every microscope, whether equipped with a substage condenser or not, is fitted with an iris diaphragm, which is of great advantage in obtaining the proper illumination. The size of the opening that should be used varies widely, depending upon the conditions, but, in general, when using a microscope without a condenser the diaphragm should be closed until the opening is just about the same size as the front lens of the objective.

Always remember, when using the concave side of your mirror, that it acts as a lens, since the rays of light reflected from it cross at a point which is known as the focus, and after crossing form an image just as a lens does. For this reason you will sometimes find that by using the concave side of the mirror you will get a better illumination of the object, since the light is brought to a sharper focus and, hence, the details of the object can be seen better than when the plane mirror is used.

Natural Light and Substage Condenser.—You will remember how the substage condenser is made, and you also know that it is used with the mirror to get the best possible light on and through the object. The principle on which the condenser works is that it brings to a focus at a point somewhere above its upper lens the parallel rays of light which are reflected from the mirror. If you want axial, or central, light, then the rays of light reflected from the mirror must be parallel. After they are brought to a focus by the condensing lens, they strike the objective in the form of an inverted cone of light, having its *base*, or large part, at the objective, and its *apex*, or point, at the conjugate focus of the condensing lens system. Whenever you use the condenser always use the plane mirror with it.

To get the correct lighting the ocular should

be removed as before so that you can see when the back lens of the objective is evenly and clearly illuminated and free from all images of surrounding objects. There are two ways that this can be done: (1) to switch from the plane to the concave mirror; and (2) to lower the condenser in its mounting a trifle by means of a quick-acting screw. Both of these methods are troublesome but they will serve to get rid of the faults.

Having obtained an illuminating field that is free from images, your next move is to adjust the diaphragm so that the right amount of light will pass through the objective. To do this, look at the back lens of the objective and close the diaphragm, which you can plainly see, until the opening in it seems to be about half as large as the objective. When you have done this the condenser is properly focused.

When you put the eyepiece in place you will probably have to make a second adjustment of the diaphragm. This adjustment differs according to the nature of the object you are examining. Thus very thin tissues when examined with a large cone of light (that is, with the diaphragm adjusted so that the opening appears to be as large as the back lens of the objective), will show up the fine details with great sharpness; this is known as the *resolving power* of the objective.

Thick tissues, however, must be illuminated by a narrow cone of light (that is, the opening of the diaphragm should never appear to be more than one half the size of the back lens of the objective, and for very thick tissues even less than this) when the greatest *penetration,* or *depth of sharpness,* will be obtained. By this is meant the power of the objective to show clearly and definitely the structure of an object which is in different *planes,* that is layers one above the other. When this point is reached it is not necessary to focus up or down in order easily to make out the details of the different layers of tissue.

Artificial Light and the Use of the Condenser.—As explained above where a substage condenser is not used you should place a bull's-eye condenser between the light and the mirror to illuminate the object. Another way is to adjust the mirror so that the light appears to be in the center of the back lens of the objective when you look at it from above through the tube from which you have removed the ocular.

If you are going to use a bull's-eye condenser, and this you should do if possible, place it so that the light passes through it and falls on the plane mirror so as to form a full sized image of the light when it is thrown on a piece of cardboard held back of the condenser. Now take away the bull's-eye and put the light in

its place, then you can focus the substage condenser so that the image of the light appears to be in the place of the object.

In focusing the condenser in this fashion you should use a low power ocular and objective. Next put the light back in its original position and replace the bull's-eye condenser, so that, as before, a sharp image of the light will be formed at the back of the condenser when a card is placed against it. A sheet of blue glass, or the blue globe, should be placed as previously described, unless *daylight glass* is used in combination with the light. The purpose of these *color screens,* as they are called, is to combine the yellow rays that are produced by the light with the blue rays and so make white light of them.

There are two things you should remember when trying to obtain the best illumination of the object by means of the axial, or central, light; (1) that a bull's-eye cannot be used unless the light is at its principal focus; (2) that a bull's-eye and a concave mirror do not work well in combination.

How to Center the Condenser.—In order to get a true axial, or central, light, it is of the utmost importance that the condenser should be *centered;* that is, the optical axis of the condenser should be coincident with the axis of the objective as well as with the axis of the

opening in the center of the diaphragm; in other words all of them must be exactly in a line. The condenser should also be centered with the light.

Every microscope is tested by the maker to see that the condenser and substage are centered, so, when the instrument comes to you, you can be sure that this happy state of affairs exists. On the more expensive grades of microscopes a means of moving both the condenser and iris diaphragm is provided. You should know how to center your own condenser in order to be sure that it is in this position before you start to work.

To do this close the iris diaphragm as far as it will go and remove the ocular from the drawtube. Now illuminate the objective by the mirror and look at the back lens of the objective. The opening of the diaphragm, if the condenser is properly centered, will appear in the exact center of the back lens of the objective and will keep this position when the latter is focused up or down to the limit of its movement with the coarse adjustment screw.

Centering the condenser is of the utmost importance, especially if you are using an immersion objective, in which case it is desirable to have the upper lens of the condenser in immersion contact with the lower surface of the slide on which the specimen is mounted. To insure

the accuracy of your centering as performed by the method just described make the following test:

Look down at the back lens of the objective with a magnifier; now, if you open the diaphragm slowly, you will see that the black ring, which is formed by the lenses of the diaphragm and is yet visible around the opening, becomes narrower and narrower until it finally disappears entirely, and all at the same time. In case the condenser is not accurately centered, the black ring will fade away more rapidly on one side than on the other as shown in Figure 24. When this takes place you will have to readjust the condenser; this you can do by using the centering screws with which the condenser is fitted.

FIG. 24.—HOW TO TELL WHEN THE CONDENSER IS OUT OF CENTER

When you are using an artificial light, make the following test to find out if it is centered: Take out the eyepiece and see whether the object and center of the back lens of the objective are illuminated. If the light is out of the center, the illumination will be to one side or the other of the object; this is easily remedied by moving the microscope or the light a little.

The Use of Oblique Illumination.—The details of some objects, such as *diatoms,* are not

brought out as well by central illumination as by what is known as *oblique illumination.* As its name indicates oblique illumination is obtained when the rays of light that pass from the object into and through the objective have their direction bent out of a line that is parallel with the optical axis; in other words, they are slantwise, or *oblique,* as shown in Figure 25.

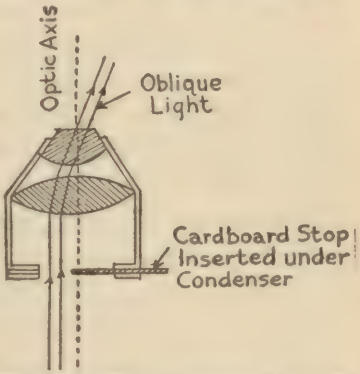

FIG. 25.—HOW OBLIQUE LIGHT IS OBTAINED

To secure oblique illumination the condenser should be centered as before and the opening of the objective flooded with the central light. Now close a part of the opening in the diaphragm by placing your finger, or a cardboard slip, between it and the mirror, when the light reflected by the latter will pass up through the open side of the condenser only, as in the figure; it will then be refracted so as to cut the optical axis of the objective oblilquely.

This kind of illumination will bring out the markings of diatoms more clearly than when the central light is used. When an object is illuminated by oblique light and the objective

is focused up or down, it will appear to sway, or shift, from side to side. When you are working with a central light and this shifting takes place, it is not the instrument that is at fault, as is usually supposed, but the fact that your illumination is slightly oblique. By turning the mirror a little one way or the other the shifting will disappear and you will then have a true central light.

Dark Ground Illumination.—When working with a true central illumination the field will be very brightly lit up and, as a consequence, the object itself will appear more or less dark. Oblique light, however, reverses this effect, for if the angle at which the rays cut the optical axis is small (this makes the rays very oblique), they will never reach the objective. This will make the field appear dark while the object which is well illuminated will appear very bright. You will find it wonderfully interesting to study specimens using first the bright background and the dark background.

How to Illuminate Opaque Objects.—In the foregoing paragraphs we assume that the object under examination was transparent, or semitransparent, and that the light was transmitted through it to the objective. Nearly all of the objects which you will examine are of this nature, but various substances, such as minerals and metals, which are opaque, must be

examined by reflected light, since light cannot pass through them.

There are two ways by which light can be thrown on an object: (1) by a mirror, and (2) by a prism. Where ordinary powers are used the concave mirror is fixed *above the stage,* and the light directed on the upper surface of the object. Another and a better way is to place a bull's-eye condenser between the light and the mirror when the illumination of the object is very strong. You must take care, though, to keep the object under examination from casting shadows.

Where very high powers are used a special arrangement is employed to light the objects. This consists of a prism which is mounted in the objective or above it in such a way that the light is refracted through it and on to the object. The use of this device is made necessary because of the short working distance which can be had with a high power objective.

With these few hints as to how to obtain proper lighting, which is more than half the game, and a little experimenting on your own hook, you will soon learn the knack of illuminating your objects so that you can get the greatest resolving power and penetration at the same time. When you can do this you will get the most pleasure and satisfaction out of your microscope.

CHAPTER VII

HOW TO COLLECT MICROSCOPIC OBJECTS

Having learned about the construction and adjustment of your microscope you are ready to begin to collect objects for examination. This is work that is interesting in itself and instructive as well. To help you make a collection to the best advantage I will tell you briefly of the different kinds of objects which you can examine and how they are related to each other. There are two principal kinds of objects on the earth: (1) *animate objects,* and (2) *inanimate objects.* The latter will be described in later chapters.

Animate Objects.—What we call animate objects are those formed of living matter, and they are everywhere about us. The study of living objects has been divided into two chief classes: (1) *botany,* and (2) *zoölogy.* Botany is the study of plant life and zoölogy is the study of animal life.

When the earth was young it was a strange place, for it was quite warm and great changes were going on, and, hence, the first plants and

animals were equally strange. These first forms of life were of a very simple nature and were, in all probability, so small that they would be invisible under a microscope of fair power. As ages rolled by some of these simple forms of life gradually changed, or *evolved,* as it is called, into higher forms of life. It was in this way that the earth in its earlier stages was the abode of gigantic fishes, lizards and flying monsters, and in its later stages the process of evolution was carried still farther and such highly complex forms of life as mammals and, finally, man came into being.

When man was evolved he was just one degree removed from his blood relation, the ape, and the dividing line between them was that the former was able to *think.* As time moved on the intellect of man evolved more rapidly and he became civilized. Civilized man has, by virtue of his ability to think, been able to piece out for his own satisfaction a fairly connected story of the evolution of the various forms of plant and animal life and of the earth's history in general.

In doing so he has found it necessary to classify the different forms of life starting with the first which was the simplest form that appeared on the earth. According to the scheme of classification there are numerous divisions and subdivisions of plants and animals. The first of

these is known as the *Kingdom* (either plant or animal). The various members of the kingdom are alike in one respect only, they are all either plant or animal forms of life.

The kingdom is next subdivided into branches, or *phylum,* as each branch is called, and in this the members all have some striking features in common. This subdivision is carried still farther into *classes, orders, families, generas* and *species.* The members of these subdivisions are more and more like one another until in some species it takes a close examination to tell one individual from another. As an illustration there are numerous species of cats, but they are like each other in more points than they are unlike. As there are over two million separate and distinct species of animals living to-day, it is easy to see why such a classification as given above is needed for the systematic study of plant and animal life.

The Divisions of Botany.—*Botany,* or the study of the plant kingdom, is divided into six chief phyla namely (1) *Algae,* which are next to the lowest forms of plant life, *Myxomycetes,* being the lowest; (2) *Fungi,* or the mushrooms; (3) *Musci,* or the mosses; (4) *Filicales,* or the ferns; (5) *Gymnospermae,* or the pine trees; and (6) *Angiospermae,* or the highest kinds of plants, in which are included the flowers.

The Division of Zoölogy.—There are a few more important phyla in zoölogy than in botany. There are ten chief phyla, as follows: (1) *Protozoa,* the lowest forms of animal life; (2) *Porifera,* or sponges; (3) *Coelenterata,* or sea anemones and corals; (4) *Echinodermata,* or sea urchins and starfish; (5) *Platyhelminthes,* or flat worms; (6) *Nemathelminthes,* or round worms; (7) *Annelida* or true worms; (8) *Arthropoda,* or jointed animals; (9) *Mollusca,* or shellfish and squids; and (10) *Chordata,* or backboned animals, which include *man,* the highest form of animal life.

It is a very good plan to fix these chief phyla of the plant and animal kingdoms in your mind so that you will have at least a general idea as to the nature of the specimens which you gather and examine. In so far as possible, I shall arrange the material for examination each in its proper place according to the foregoing classification, and your work with the microscope will not only be of great interest but you will learn a great deal at the same time.

Your Collecting Outfit.—To collect specimens which will become objects for your microscope, you will need an outfit composed of a few simple articles, most of which you can make yourself and the rest of which you can buy for a small amount from any dealer in microscopic supplies. With this outfit you can gather speci-

mens from both the pond and field and carry them to your laboratory where you can examine them at once or mount them for future use.

Your outfit should include (1) a *magnifier;* (2) a *light bamboo pole* with (*a*) a *hooked knife blade,* (*b*) a small *conical bag,* and (*c*) a *bug net;* (3) *two glass bottles;* one of these should be a 4-ounce, wide-mouthed bottle with a brass ring fitted to its neck, and the other a 12-ounce, wide-mouthed bottle fitted with (*a*) a two-hole rubber or cork stopper (*b*) two small glass funnels, and (*c*) some short lengths of rubber tubing; and last of all (4) a *collecting case.*

The Magnifier.—This lens has been described in Chapter I. You will find it very useful when you are in the field to see your specimens to better advantage than you can with the naked eye.

The Bamboo Pole.—This can be made of a piece of a fish pole 3 or 4 feet long. One end should be fitted with a threaded metal tip so that you can screw it into the sockets of the various accessories which you have and so serve as a handle for all of them.

The Attachments.—You will have to buy the hooked knife as it is of peculiar shape. One end of the blade is fitted with a threaded socket in which the bamboo handle can be screwed. With this knife you can cut plants loose from the bottoms of shallow ponds and bring them

to the top. The small conical cloth bag should be about four inches in depth and diameter. It should be made of a good quality of cheesecloth and its mouth sewed to a wire ring which is fitted with a socket for the handle.

This bag will be found very useful in collecting specimens for your microscope, as the water will drain off and you can then examine the contents with your magnifier to determine those

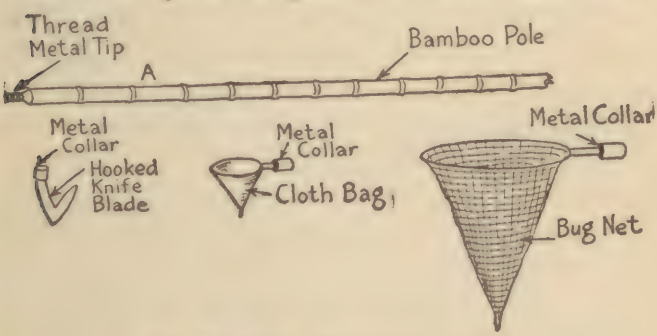

FIG. 26.—YOUR COLLECTING OUTFIT

that are worth keeping. The *bug net* is made of very fine mosquito netting or bobinette and is of the same shape as the cloth bag; it is about one foot in depth and diameter and is sewed firmly to a wire ring which can be screwed on to the handle. This net will be found of value for the capture of flying insects as well as for small aquatic animals such as tadpoles and minnows. All of the various parts of this outfit are shown in Figure 26.

Two Glass Bottles.—The small, four-ounce glass bottle is fitted with a brass ring which clamps around its neck, and this is fitted with a socket for the handle. This arrangement is useful for scraping the bottoms of ponds and creeks. You need only to collect a bottleful of

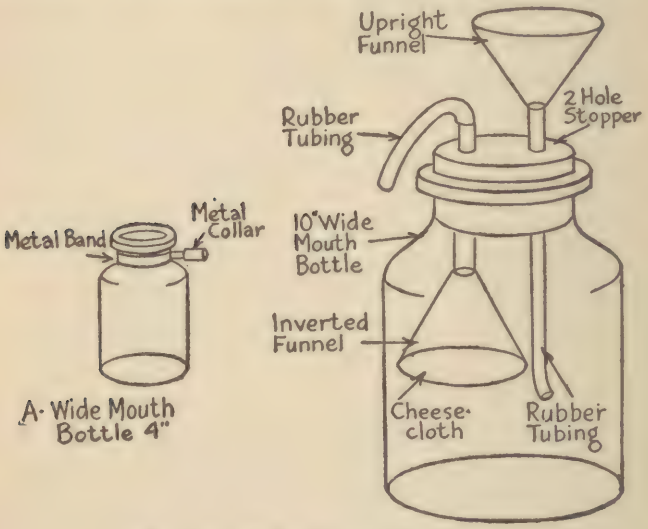

FIG. 27.—THE GATHERING BOTTLES

material from such sources you will find it fairly swarming with all kinds of animals and vegetable life, and it will provide you with an endless number of specimens for your microscope.

The 12-ounce, wide-mouthed bottle is fitted with a rubber or cork stopper with two small holes in it just large enough for the stems of the

glass funnels to go through. The stems are pushed through the holes so that the mouths of the funnels are on opposite sides of the stopper. The mouth of one of the funnels is then covered with cheesecloth, and the stems of both are fitted with short lengths of rubber tubing, all of which is shown in Figure 27. This large bottle will be found very convenient for transporting the larger forms of life, such as tadpoles, minnows and crayfish from the hunting grounds to your workroom.

The way to use the bottle is this: after you have collected some specimens with the small bottle, either remove the cork if they are large and lively, or pour them through the funnel which projects from the cork if they are small enough to go through the stem. Then fill the bottle about three-fourths full of water taken from that in which the specimens were gathered, as they will live longer and be in better condition for examination if this is done. When you get home you can drain off the water by inverting the bottle when it will run through the inverted funnel and the specimens will be held back by the cheesecloth.

The Collecting Case.—This is the last of the accessories which go to make up a good collecting outfit. This consists of a flat, enameled tin box of such a size that it can easily be carried around in your pocket. It is divided into from

six to 12 compartments and each compartment contains a small bottle. It is easy to transport the more or less minute forms of life in this case, and it enables you to keep the different specimens you may collect separate.

Taking Care of Your Spoils.—When you have returned home after a day in the field, the first thing to do is to overhaul your spoils, separating those specimens which can be examined while living from those which you want to mount and keep permanently. You will no doubt find in your collection of minute living plants and animals fine specimens of the water flea, hydra, algae (free-swimming), rotifers, etc. of which more will be told in another chapter.

All of these specimens are suitable for examination while in the living state, and you will find a small aquarium just the thing to keep them so that they may be examined from time to time. You can make one of a perfectly clean, deep glass bowl, or a regular fish bowl, covering the bottom with small clean pebbles and then placing on them some easily growing water plants.

Fill the bowl nearly full of clean fresh water and lay a sheet of glass over the top; then raise one side of the glass a little to admit air and your aquarium is complete. Your specimens may be transferred to the aquarium, and if you

change the water frequently they will live for a long time.

How to Examine Living Specimens.—To prepare the living objects which you have gathered for examination you must first get a couple of *dissecting needles,* one of which has a straight and the other a bent tip as shown at *A* in Figure 28. These are ordinary needles mounted in wooden handles.

You will also need a *pipette,* which is a small

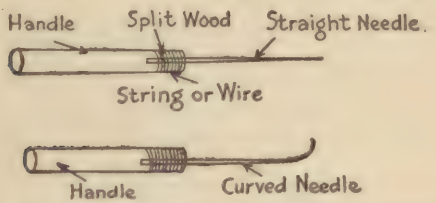

FIG. 28.—TYPES OF DISSECTING NEEDLES

glass tube with one end drawn to a point and a rubber bulb on the other end as shown at *B*. You can get one in any drug store for five cents by asking for a *medicine dropper.* Or you can use a plain glass tube open at both ends. Dip this into the bottle that contains the organisms you want to examine, place your finger over the top, then withdraw the tube and the contents will not run out. To release the contents you need only to lift your finger from the top.

Finally, you should have a small shallow dish and a life slide. To use this equipment trans-

fer a small quantity of the water containing the living organisms to the shallow dish then examine it with your magnifier. For this purpose you can use to good advantage the tripod magnifier, described in the first chapter, when you can discover whether you have any live objects mixed in with the filaments which you will find in the water. The filaments can then be separated with a dissecting needle, and by means of the pipette a tiny fragment can be transferred to the life slide.

The life slide is a piece of glass one inch wide and three inches long, in the center of which is ground out a little cavity. The object to be examined is placed with a drop of water on the center of a cover glass, which is a thin piece of clear glass of the same size as the life slide. The cover glass is then inverted and the drop will hang down, clinging to the under surface by the force of adhesion.

Now place the cover glass with the drop hanging to it directly over the cavity and the life slide and on the latter. This done, insert the slide under the spring clips on the stage, then the microscope can be focused and you can examine the object. The cavity in the slide is large enough so that the living organism has room enough to swim about in the drop of water. A life slide can be bought for 25 cents; it is shown at *A* in Figure 29.

You can easily make a substitute for a life slide out of a piece of cardboard. First cut it to the size of an ordinary glass slide, then cut a hole in the center about the size of a lead pencil, or a little larger, as shown at *B*. Now place the perforated piece of cardboard in an ordinary slide and transfer a drop of water containing the living organism to the hole with

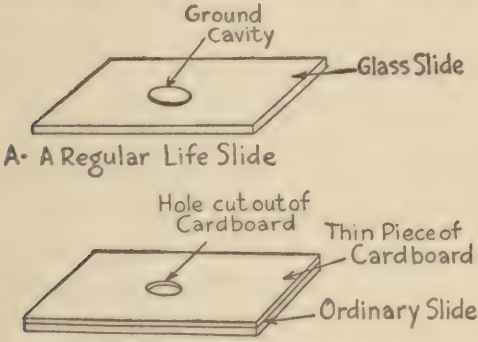

FIG. 29.—KINDS OF LIFE SLIDES

your pipette. In doing this press the cardboard firmly down on all sides, then place a cover glass on the cardboard, and you will have an improvised cell with a cavity in it like that of a regular life slide.

How to Examine Objects in the Dry State.—Such objects as small insects and the like must be examined *dry*, and for this purpose you can either use the life slide and place the insect, if it is small enough, in the cavity, or you can make an improvised forceps in which the insect

can be lightly but firmly held and moved about under the objective. This you can do by using a cheap drafting pen [1] and clamping some small part of the insect between the points. The pen should have a short handle, or you can cut off the handle, so that it will not over-balance when laid on the stage of the microscope.

The head of a living insect, such as a fly, can be examined in the following manner. Make a small cone of paper and glue the edges together so that it will stay put. Next cut off the point of the cone so that a hole will be formed that is just large enough to admit the fly's head, but not large enough to let him escape. Put the fly into the mouth of the cone and it won't take much manipulation on your part to make him stick his head through the opening. Once he does this, stuff the wide mouth of the cone full of cotton to keep him in place. You can then watch him as he moves his head about and you will learn something about a fly's eyes and proboscis that you did not know before.

[1] Can be bought at stores where drawing instruments are sold.

CHAPTER VIII

HOW TO DISSECT, MOUNT AND STAIN OBJECTS

After you have looked over the living specimens you have gathered, you will, doubt, find some among them which you would like to preserve for future examination. Now the process of preparing an object so that you can see it through your microscope to the best advantage is called *mounting* it. There are quite a number of ways to *mount* an object; some are quite simple and others are difficult.

About Mounts and Mounting.—In its simplest form a mount consists of a slide of perfectly clear glass, that is glass which is free from flaws and air bubbles and which is one inch wide and three inches long. When the object is secured to this slide and a cover glass, which is a much thinner piece of glass and either round or oblong like the slide, is fixed on top of it, the whole thing is called a *mount*.

While a great many of the lower forms of plant and animal life are small enough to be mounted and examined when whole, the higher

forms of life have to be examined piecemeal, and the higher the power of the microscope the smaller the section or part of the object that can be seen with it at one time. It is necessary then with objects which are sufficiently large to be visible to the naked eye to *dissect* them, that is cut them into minute pieces and these again into thin slices so that they may be studied one at a time. In this way a detailed knowlege of the object as a whole can be had.

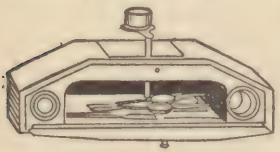

FIG. 30.—A SIMPLE DISSECTING MICROSCOPE OUTFIT

What a Dissecting Outfit Consists of.—To prepare an object for mounting as described above, you must have a *dissecting set.* This consists of (1) two needles as shown at *A* and *B* in figure 24; (2) a pair of small, sharp, pointed scissors; (3) a pair of forceps, or small tweezers; (4) a section knife; and (5) a dissecting microscope. This outfit is shown is Figure 30 and can be bought complete for about $5. You can make a dissecting microscope of a cigar box or other thin wood, and mount a magnifier on top of it, but if you inend to do really good work you had better buy one ready to use.

The Dissecting Tools.—The dissecting *scissors* should be very sharp and have pointed blades which are slightly curved. A pair of

manicure scissors will serve your needs very well. The *forceps* are a pair of light tweezers such as milady uses to pluck out a superfluous hair, and can be bought in a drug store. There are various kinds of *section knives,* the simplest and cheapest of which is the *scalpel* shown at *A* in Figure 31.

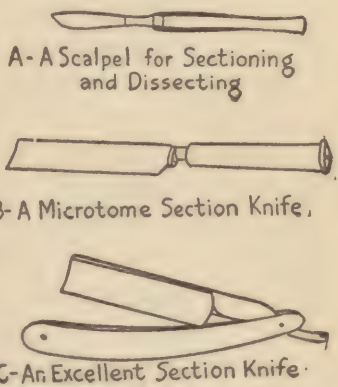

FIG. 31.—KINDS OF SECTION KNIVES

As a makeshift you can use a steel ink eraser, or you can make one by fixing the blade of a safety razor in a wood handle. A better and more expensive knife is shown at *B* and a razor *C* makes a very excellent knife, but you must be careful how you handle it. There are machines called *microtomes,* made for slicing objects, and in Chapter XV you will find directions for making a simple one.

The Dissecting Microscope.—This consists of a stand fitted with a magnifier which is mounted over a glass stage; on this is placed the object you are going to dissect. An adjustable mirror is placed underneath this stage so that the object can be illuminated. By rigging up a

magnifier so that you can see the object to be dissected without having to hold it, you can get along without the dissecting microscope, but as the latter costs only $2 or $3 you should get one if possible. Chapter XV also tells how to make a simple dissecting microscope at a cost of $1 or even less.

How to Dissect a Specimen.—Before you try to dissect an insect or other animal you must, of course, kill it. This you can do by putting it in a bottle containing a bit of cotton saturated with chloroform and leaving it corked up tight for an hour or so. Now lay the insect under the lens of the magnifier and focus it until it is as large and as sharp as possible. Then grip some part of it, such as a wing, a leg or an *antenna*,[1] with your forceps when it can easily be cut from the body with your scissors. In this way you can readily dissect, that is, cut up, the animal into its component parts when they can be mounted.

While the above method is used for removing the external parts of the animal, the interior portions of it must be taken out by a different process. To do this, place the animal on a thin piece of board and stake its legs and wings out firmly with pins so as to leave its body open for dissection. If you want the abdominal[2] or

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1 Commonly called its feeler.

2 The stomach. In insects and some other arthropods it is the hindmost of the main divisions of the body.

magnifier so that you can see the object to be thoraic [3] regions bared stake it out, back downward, on the board; if you are after its nervous system you should have it on its stomach so that you can operate on its back. Place the board in a shallow dish of water then the skin on either side of the abdomen or thorax can be lightly cut through with your dissecting scissors after you remove the skin with your forceps the internal organs can easily be taken out.

The stings of wasps and bees can be removed by holding the abdomen of the insect between the thumb and forefinger of the left hand and gently squeezing it. This will force the sting out a little way, then you can pull it out of its body with your forceps, and the poison gland and duct will come out with it. To remove the gizzards [4] of beetles, or the salivary glands [5] of crickets and cockroaches, soak the specimen for several days in water until it softens up enough so that you can pull off the head when held lightly with the forceps. If you perform this operation carefully enough the esophagus,[6] salivary glands and stomach organs will come out with it.

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[3] Of, within, pertaining to, or connected with the chest, the next region in front of the abdominal.

[4] In insects this is the first stomach.

[5] A gland that produces saliva.

[6] The tube through which food and drink pass from the pharynx to the stomach.

How to Section Object.—Sections of objects which you want to mount for examination may be as thick as one millimeter or as thin as 1/1000 of a millimeter. Such very thin sections as the latter can be cut only by means of an expensive microtome and the object must be either frozen or embedded in paraffin so that the cells of which the tissue is built up will hang together after it has been shaved to this micrometric thinness.

For most microscopic work, especially at the beginning, you can use such sections as you can slice off with a section knife. If the object that you want to section is firm enough you can easily cut it off to one-half millimeter in thickness. Grip the object between the thumb and forefinger of your left hand, then use your thumb nail as a guide for cutting it. Use a sharp scalpel or section knife and draw it across the object toward your body.

A great many objects are too soft to be cut in this fashion. Plant stems and leaves are of this kind; consequently these must be embedded in pith and then cut. To do this take a piece of elder pith and cut a slit in it large enough to insert to object to be sectioned. Then tie a thread around the pith near the end so that it will firmly hold the specimen in place. You can now hold it under the lens of the dissecting microscope and cut it into sections.

Other objects which are even softer than plant tissue, such as animal tissue, must be embedded in paraffin in order to cut them thin enough so that the sections will be transparent under the microscope. To do this put some paraffin in a tin pill box and heat it gently until it melts; now dip the object in it until it is thoroughly saturated and then cool it quickly by holding it in a stream of cold water. This is a secret of successful sectioning, for if the paraffin is allowed to cool slowly crystals will be formed which will prevent you from cutting a clean section. After a section is cut the next step is to mount it.

How to Mount Objects.—You will remember I told you in Chapter III how the cover glass causes aberration as well as the air between the cover glass and the objective, and how these can be overcome. In spite of the precautions, aberration will still take place if the object itself is not mounted in a proper medium. Another thing to be taken into account is that different media must be used for mounting different kinds of objects to bring out the structural details the better.

Kinds of Mounts.—There are two kinds of mounts which are most often used for microscopic objects; (1) *temporary mounts,* and (2) *permanent mounts.*

Temporary mounts are suitable only where

you want to examine the object at once and do not need to preserve it for future use. They are very easy to make as all you have to do is to place the object, whether it is a plant or an animal tissue, crystals or viscous substances, such as paint, glue, etc., on the center of a glass slide, then place a cover glass on it; for viscous substances work the cover glass back and forth, using the rubber on the end of a lead pencil to do it. The purpose of this is to distribute the substance evenly on the slide and at the same time get out all the air bubbles.

Permanent mounts are objects so mounted that they will keep for an indefinite length of time. These are of two kinds: (1) those in which air is used as the medium; and (2) those in which glycerin or balsam is used as the mounting medium. In nearly all cases the latter mounts will give the best results and greater permanency than the air mount, because (*a*) nearly all objects contain more or less water, and (*b*) both glycerin and balsam have high indices of refraction and tend to make objects which are more or less opaque more transparent when mounted in them.

Objects which contain considerable water are not suitable for air mounting, as the water will gradually dry out, and, as it does so, the cellular structure becomes distorted, aye, worse, the action of the air causes decomposition of

the tissues to set in. Objects such as bone, stone and crystal sections, the wings, stings and other fairly dry parts of insects may be permanently mounted in air, or in a *dry mount,* as it is called.

How to Make Air Mounts.—The first thing to do in making any kind of a mount is to use slides and cover glasses that are absolutely clean. To clean these properly wash them in xylol then place them in a solution made of equal parts of water and alcohol until you are ready to use them. From now on handle them as carefully as you would a lens. There are four steps in making an air mount: (1) building up a cell on the slide; (2) fixing the object in place; (3) attaching the cover glass; and (4) labeling the slide.

Some sort of a cell, like a little well, is needed to keep the cover glass from resting directly on the slide and injuring the object. To make a cell, dip a small camel's hair brush in shellac, marine glue or asphaltum varnish [7] and make a small, thin ring of it on the slide. When this ring has dried put on another ring and repeat this process until a cell is formed of the proper depth. The easiest way to do this is to make a small turntable of wood and fix a support to it to hold the brush as shown in Figure 32. You can easily make one of these turntables by using

[7] These are called cements.

the picture to go by and following the dimensions marked on it.

The handle of the brush is pivoted in the slot with a screw so that when it is dropped the camel's hair end rest on the glass slide. Now when you dip the brush in the cement and let it rest on the slide and rotate the disk of the turntable with your finger, an even ring of ce-

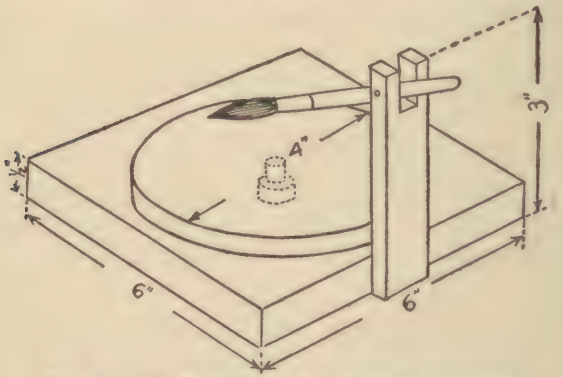

FIG. 32.—HOW TO MAKE A SIMPLE TURNTABLE

ment will adhere to the slide as shown in Figure 33.

The depth of the cell you need will, of course, depends on the thickness of the section of the object you are going to mount. If the object is quite thick, say one millimeter, then you can cement a paper, wood or fiber ring to the slide to give the cell the right depth, as this is easier and quicker than building it up on the turntable.

However the cell is formed the object should

be fixed inside it to the slide, or to the lower side of the cover slip by means of a cement called *Mayer's Albumin Fixative*.[8] To use it, place a drop on the cover slip or slide, whichever you intend to fasten the object to, and rub it with your finger until only a thin film is left; now place the object on it and it will be firmly mounted after it dries. The next step is to secure the cover glass to the slide.

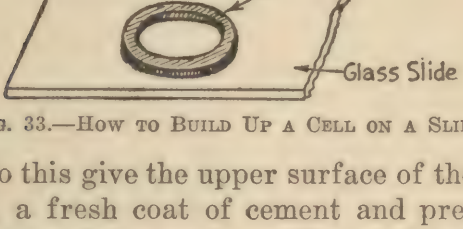

FIG. 33.—HOW TO BUILD UP A CELL ON A SLIDE

To do this give the upper surface of the ring, or cell, a fresh coat of cement and press the cover glass down on it gently but firmly. A light coat of the cement should then be labeled so that you can tell what it is at any time. A cabinet is a very handy piece of furniture in which to file your slides.

How to Make Glycerine Mounts.—Certain objects, such as plants, should not have the water which they contain removed from them

[8] You can make this by mixing about 50 cubic centimeters of pure hen's egg albumin (the white of the egg) with an equal amount of glycerin, then add one grain of sodium salicylate to it. Shake well and filter and it is ready for use.

when they are mounted, and to mount them so that they will neither shrivel nor decay use the following method: melt some glycerin jelly[9] slightly and then place the object to be mounted in the position on the slide where you want it; cover the object with a little jelly, place the cover slip over it and set it aside to cool and harden. One of the advantages of using a glycerin jelly mounting is that you do not need to build up a cell on the slide or cover glass. Its disadvantage lies in the fact that it is not altogether permanent and better results are obtained in many cases by mounting the object in balsam.

How to Make Balsam Mounts.—Before you can mount an object in balsam[10] it must be put through the following four processes: (1) *fixation;* (2) *dehydration;* (3) *staining;* and (4) *clearing.*

Fixation.—This means that the cell structures of the object must be so treated that they will remain in the same shapes as they were when the plant or animal was alive. This is done by putting the object through a *fixing solution* that hardens the cells so as to prevent them

[9] This can be made by soaking 1 part of gelatin, by weight, in 6 parts of water, to which an equal quantity of pure glycerin is added, together with a few drops of carbolic acid.

[10] Canada balsam, or balsam, as it is called for short, is a resin obtained from the balsam tree.

from being distorted while they are being mounted, or afterward.

For the fixing solution you can use either a saturated solution of corrosive sublimate, or a weak solution of 30 per cent alcohol made by mixing one pint of pure alcohol with two parts of water. The object should be left in this solution from 15 to 30 minutes when the tissues will have hardened and the cells will keep their original positions.

Dehydration.—After *fixing* the object it must be *dehydrated,* that is, the water which it contains must be extracted from it. This must be done gradually and is accomplished by placing the object in successive solutions of alcohol of different strengths, the first of which is 50 per cent, the second 75 per cent, the third 90 per cent and the fourth and last 95 per cent alcohol. If the object were plunged into a 95-per-cent solution of alcohol at first dehydration would take place so rapidly that the cells would be distorted. Leave the object in each of these baths for about five minutes if small and from 10 to 15 minutes if large.

Staining.—While you need not stain an object unless you want to, it is well worth while to do so, as staining causes the different kinds of cells which form the tissue and which have different chemical compositions to take on distinctive tints, and these make them stand out separ-

ately and very clearly when you examine the object with your microscope. All you need to do is to dip the object in a solution of *borax carmine* or *alcohol carmine*[11] for a few minutes when the various cells will be dyed distinctive tints.

Clearing.—Finally the object must be *cleared,* that is, the tissues or cells must be penetrated by a liquid that has an index of refraction about equal to glass. For this purpose a liquid must be used that will mix equally well both with alcohol and the balsam in which you are going to mount the object. For this purpose you can use cedar oil, or xylol can be used instead where a section has been cut while embedded in paraffin, as this is a solvent for the latter.

Balsam as a Mounting Medium.—Canada balsam makes the most permanent mounting for most objects, because, when it sets, it becomes nearly as hard as a rock. Further, it has an index of refraction and this makes objects that are naturally more or less opaque more transparent; and, finally, it very largely overcomes the aberration of the rays of light that pass from the object through the cover glass.

To make a balsam mounting, mix a little balsam with an equal amount of xylol, which, as I said before, is a solvent for it. Next place the

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[11] You can buy these of a dealer in microscopic supplies.

object on the slide and cover it with this mixture, and then place the cover glass lightly over it and set it aside. The xylol will evaporate and the balsam, when it sets, will be as clear as a crystal.

CHAPTER IX

PLANT SPECIMENS UNDER THE MICROSCOPE

As I have already explained, the right way for you to examine living objects is to *know* what you are examining, that is, to just what phylum of plants or animals they belong. Unless you go about the subject in this way you can never hope to be much of a microscopist, for while you will find the objects that you examine interesting enough you will not get their true meaning.

Further, it is much more pleasurable and instructive to look at objects under the microscope when you know a little about their nature and structure beforehand, as this gives you a hook on which to hang your investigations. In beginning your examination of plant specimens you should start in with the lowest forms first and learn about their structure and methods of reproduction, then go on up the scale step by step until you reach the highest type. By so doing you will get a clear insight into the more complex forms.

Algae, a Very Low Form of Plant Life.—In beginning the systematic examination of plant specimens you should start in first with *algae,* which is a very low form of plant life. These minute living organisms are found in one form or another in all parts of the world, and they seem to thrive in any climate however hot or cold.

The most common kind of algae is sometimes wrongly called "*frog spittle;*" this is the green scum that is found floating on the surface of small ponds and lakes.

If you will examine a minute bit of any of the algae under your microscope, you will see that they are, in general, built up of a large number of green cells. Each of these cells is made up of protoplasm, which is the basis of all life, be it vegetable or animal. Four regions may be seen: (1) a *nucleus,* formed of an albumin-like[1] substance which is the center of the vital activity of the cell; (2) *cytoplasm,* which surrounds the nucleus; (3) chlorophyll corpuscles, or particles which are located in the pores of the plant and are acted on by light (they are really a special kind of protoplasm made up chiefly of green coloring matter), and (4) a cell-wall, which encases the whole.

Chlorophyll (the Green Coloring Matter of Plants).—The chlorophyll corpuscles, or par-

[1] This is a *protein* and one of the familiar kinds is the white of egg.

ticles of green coloring matter, carry on the important work in plants of breaking up the *carbon dioxide,* a gas which the plant absorbs, or inhales, from the air, into the *carbon* and *oxygen* of which the gas is made, and *fixes* it, that is, combines it with the *hydrogen* and *water* in the cell; this makes *starch.* During this process the oxygen of the carbon dioxide is freed and returned to the air.

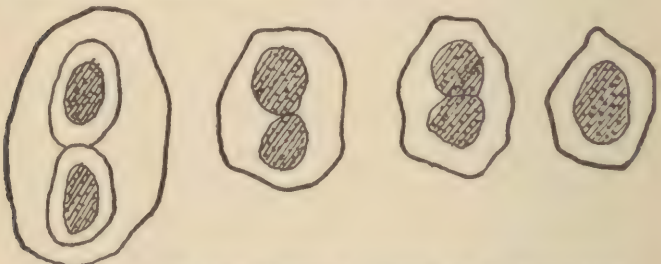

FIG. 34.—HOW CELL DIVISION OCCURS IN PALMOGLAEA

The grains of starch are formed in the inside of the plant cells; as they grow they gradually fill the whole cell cavity and push the protoplasm to one side. To see this more clearly, stain a specimen with a *dilute solution* of *iodine* and *alcohol;* this will turn the starch blue, when it will stand out much more distinctly.

To watch algae growing under the microscope is very fascinating; this is particularly true of the kind called palmella, which is the green slime that forms in damp places. An examination of the cells of this plant will show that each one gradually divides itself into two

parts as in Figure 34, each part being surrounded by a gelatinlike substance which joins them together end to end. This method of growth is more or less common to all the lower forms of plant life.

Conjugates or Green Algae.—This is another kind of plant life a little higher in the scale than "frog spittle" and green slime. These little plants have the curious property of conjuga-

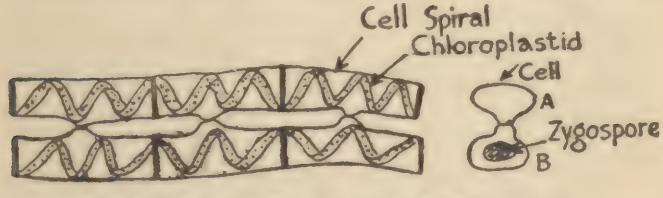

FIG. 35.—HOW CONJUGATION IS CARRIED ON

tion, that is the cells unite or fuse together; this they do as follows: each cell pushes out a portion of its walls, and, on coming in contact with each other, the two cells are joined together as shown at *A* in Figure 35; gradually these extended parts broaden until the cells become fused into one large cell. Of this kind of algae the Spirogyra, the most common genus, and all of its species are of special interest, owing to the peculiar and distinctive spirals which are formed by the chlorophyll bodies in the cells.

The final stage of the conjugation of this plant consists of the formation of *zygospores*

(pronounced *zi'-go-spores*) as shown at *B* in Figure 35; these are like the seeds of a flowering plant in that they can remain in a *quiescent,* that is, dormant, state for a nearly unlimited time, and still retain the germ of life. Indeed, they may seem to be completely dried up and dead, but if they are planted in a suitable soil and under favorable conditions they will shortly begin to show signs of life; further, they will multiply as I have previously explained and thus cause the plant to grow through the continued process of conjugation. Spirogyra may also reproduce by the simple dividing of the individual cells into two.

Diatoms, a Branch of the Conjugates.—A most highly interesting branch of the unicellular algae is the *Diatoms,* or *Diatomaceae,* to give them their scientific name. These are simple, single cells that have a delicate, brittle coating of a mineral substance known as *silex*[2], or *silica.* This outside coating is the distinctive feature of this group of algae, and gives rise to the peculiar markings on the surface of the cells as shown in figure 36.

The general structure of the cell, with the exception of the *silicious* cell wall, has already been described. The protoplasm, however,

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2 *Silex* and *silica* are the same thing. It is a hard, white, colorless, crystalline *silicon dioxid* (Sio_2) that is found pure in many rocks and sands.

contains a substance called diatomin, which takes the place of chlorophyll, giving the plant a yellowish brown instead of a greenish color. If, however, it is moistened with a dilute solution of *sulphuric acid* the plant will take on the green color of most algae, showing that the diatomin has been changed to chlorophyll.

A curious property of *Diatoms* is the power of movement that some of of the species have, and so marked is this that many of the early botanists believed that they were of animal rather than of plant origin.

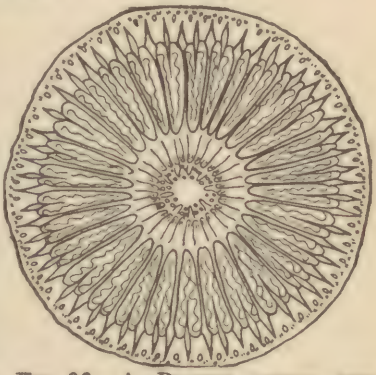

FIG. 36.—A DIATOM UNDER THE MICROSCOPE

Diatoms reproduced by the process of conjugation or by means of the process of cell division. In order to see the markings of the *silicious* cell to the best advantage, you must first boil the diatoms in dilute *sulphuric acid*; then wash and boil them in soapy water to further clean them, then wash again in clean water; after this they can be dried and mounted either dry or in balsam.

Plants of the Fungus Group.—The next higher family of plants are those of the fungus

group, or *Fungi.*[3] These plants differ from algae in that the protoplasm contained in the cell does not have any chlorophyll mixed with it, consequently, they are without color. The lack of the chlorophyll prevents the plants from being able to form starch directly, as do the algae, by the decomposition of *carbon dioxide* and *water.* The result of this is that the members of the fungus group cannot get their nourishment from the air but must live on other food materials, such as decaying vegetables and animal matter, or on the tissues of living plants and animals.

Those fungi that feed on the dead tissues of plants and animals are known as *saprophytes,* while those that feed on the living tissues are known as *parasites. Bacteria,* or *germs, as* they are commonly called, are fungal parasites, and many of the diseases of plants and animals are due to them. The study of parasitic bacteria which cause diseases in the human body is of the greatest importance, for by it such virulent diseases as typhoid fever, smallpox, etc., are successfully combatted.

Kinds of Fungi.—In general, there are three kinds of *Fungi;* (1) those forms that go by the name of *mold, smut* and *rust;* (2) those that grow in fresh and salt waters, and (3) the

[3] The plural of *fungus.*

higher forms, which include *toadstools* and *mushrooms.*

Of the first kind you will find the family known as *mucorales* of interest. The most common member of this family is the one that has a growth of hairlike filaments and is called the *Mucor Mucedo;*[4] it makes its appearance on decaying plants and vegetables. This fungus reproduces by means of *spores* or *gonidia* which are held within a *sporangium* fixed to the outer end of the long, threadlike filament (see Figure 37), of which the mold consists. Look at it under your microscope and you will see that the sporangium is covered with "warts" and other *protuberances* or swellings.

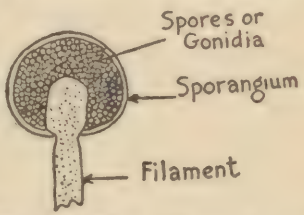

FIG. 37.—THE SPORANGE OF MUCOR MUCEDO A FUNGUS

Still another family which is closely related to the *Mucorales* is the *Entomophthorales* (pronounced En″-to-moph-thor-al′-ees); this is a parasitic fungus which gets its nourishment from the living tissues of flies, caterpillars, and other insects. One member of this family attacks the common housefly by means of a spore which attaches itself to some part of the

[4] This is any fungus growth on food, clothing, walls, or decaying vegetables.

fly's body where it germinates and finds its way into the interior of the host,[5] through the rings of its body or through its breathing pores. Once the spore has made its way inside the host it sends forth germinating filaments and finally spreads through the whole body and causes the insect's death. After the death of its *host* this parasite thrives even better, and the outside surface of the fly becomes covered with the sporebearing filaments.

Some of the plant parasites are, however, not only harmless but beneficial to the human race, such as common *yeast*, the scientific name of which is *Saccharomyces cerevisiae*. Now, if you examine a minute drop of yeast with a microscope having a magnifying power of 400 or 500 diameters, you will readily see that it is made up of a large number of globular cells.

These cells have been found as small as 1/3000 of an inch in diameter, and they have the peculiar property of growing or multiplying very rapidly when placed in a fluid which contains *nitrogen*; they can also be fermented. This growth, or multiplication, of the yeast cells is so great that in the course of a few hours they will increase at least sixfold if not more. During the process of multiplying, *carbon dioxid* is set free from the mixture; it is this gas that causes bread dough to rise.

[5] Any organism that harbors another as a parasite.

The Mushroom Family.—Finally there is the kind of fungi known as *Basidiomycetes* (pronounced Ba-sid″-i-o-mi′-ce-tes) which includes *puffballs, mushrooms* and *toadstools.* The spores of this family are formed at the apex, or top, of specially enlarged cells, or *basids* as they are called, which are located in the umbrellalike tops of the plant. This receptacle is known as the pileus and is supported on top of a stalk or stipe. To examine these plants you must dissect the pileus so that you can get at the spores which the basids contain.

The Phylum of Mosses, or Musci.—The next higher branch of plant life is the *mosses,* or *Musci,* as they are called. Members of this phylum have a distinct axis of growth, that is, a line around which a stalk grows. This axis is usually, but not always, upright, and around it the little leaves are symmetrically, that is, evenly arranged. It is a characteristic of the mosses which are higher in the scale of plant life that the stem structure is prolonged so as to pass into the leaves, thus forming a midrib, such as is found in the highest forms of plant life; further, the mosses approach the higher forms of plant life in that they are provided with rhizoids or root hairs which take the place of true roots.

The moss plant consists of (1) the *rhizoids*; (2) its *leaves* located at the base of the plant;

(3) the *antheridia* and *archegonia,* which are the male and female reproductive organs, and are placed close to the axis and at the apex of the leaves; (4) the *setal,* or *footstalks*; (5) the *sporangia* wherein the spores are held until (6) the *caps,* or *opercula,* fall off and set them free as shown in Figure 38.

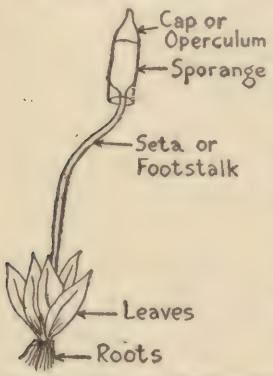

FIG. 38.—THE STRUCTURE OF A TYPICAL MOSS PLANT

You should examine all these parts under your microscope; to do this you will have to dissect the plant with your dissecting microscope. The various parts may then be examined while dry, or, better, when mounted in balsam. Go carefully into the structure of the mosses and you will pave the way for an easy understanding of the plants that are next highest in the scale, namely the *ferns* or *Filicales.*

The Phylum of Ferns, or Filicales.—In the ferns for the first time you will find a stem structure that is anything like that of the true flowering plant. The ferns differ from the mosses in that they have what is known as a *vascular system,* that is, a stem made up of wood tissues which have a series of *fibro-vascu-*

lar bundles which contain the ducts and vessels through which liquids are drawn into the plant. The bundles make up a kind of network, and from these prolongations extend which lead into the leaf stalks and from the latter into the midrib and its branches.

The sporangia of the fern grow on the under side of the leaves, or *Fronds,* and are contained *in sori*[6] which are cuplike receptacles that have caps over them; these latter are composed of a thin membrane known as *Indusium.* If you will place some of the *sori* under your microscope you will find that they are made up of a large number of sporangia. In some species these are attached directly to the under surface of the frond, and in others a *pedical* or footstalk forms the attachment.

If you will examine a number of these sporangia you may be fortunate enough to see them burst and scatter the spores, which are angular in form, and have a yellowish-brown color. The *antheridia* and *archegonia* are found in the minute structure called prothallus, which develops from a spore, but not in the mature fern itself; it is this feature that distinguishes them from the lower plants.

The Pine Tree Family, or Gymnospermae.—You are now ready to take up the examination of plants which produce true seeds and then

[6] Plural of sorus.

those that are true flowering plants. The lowest order of these plants is known as *Gymnospermae,* and all members of it, which include such trees as pine, cedar, fir, cypress, hemlock and spruce, produce *naked seeds.* The pine tree, which belongs to a subdivision of the *Gymnospermae* known as the *Coniferales,* and hence called *Conifers,* bears a seed which is formed and fertilized while still on the parent plant and which is nourished by the latter until it has matured and carries a sufficient store of nutriment to supply, the already well-developed embryo along until it is in a late stage of germination.

The Family of Flowering Plants, or Angiospermae.—There is very little difference in the structure of the pine tree family and the highest forms of plant life which are known as *Angiospermae.* The chief differences otherwise between them are (1) that the angiosperm produces a covered seed which is contained in a *capsule, pod,* or *pericup,* as it is called; and (2) that the angiosperms are flowering plants while in the gymnosperms the chief parts of the true flower are often lacking. A brief description of the structure of the various parts of these plants will be useful to you when examining them under your microscope.

The Cells and Tissues.—In general the higher plants are composed of a soft cellular sub-

stance or tissue which is found wherever points of the root fibers, leaves and buds and in the flowers in their reproductive parts. The woody tissue, which is found in the stems, branches and roots of the higher plants, serves two purposes: first, it acts as a support for the softer tissues inside; and, second, it forms ducts to carry fluids from the roots up through the stem and branches to the leaves.

The soft cellular tissues that are inside the stem are formed of cells which have a more or less globular shape. In the more woody tissues the cells are pressed closely together so that while still remaining rounded they are at the same time considerably flattened. In the growing tissue new cells are formed by cell division, that is a new cell wall is formed across an old cell, thus dividing it into two equal cells which proceed to grow and divide in a like fashion, thus carrying on the growth of the tissue. I have already told you how starch is produced in chlorophyll-containing cells of all plants by the decomposition of *carbon dioxide gas.* Such cells occur only in the outer exposed layers of plant tissue.

The woody fiber, or tissue, of the higher plant is a variety of cellular tissue as described and deposits *sclerogen,* which is a substance closely allied in chemical composition to *cellulose;* this thickens them until the original cavities of the

cells are almost filled with it. The result is that the tissue, which is found everywhere in the plant where there are vessels or ducts which need its protection and support, is toughened.

The Roots and Stem.—The angiosperms, or higher plants, are divided into two groups, (1) the *monocotyledons* (pronounced *mon-o-cot"-i-le-dons*), and (2) the *dicotyledons* (pronounced *di-cot"-i-le'-dons*); you can easily tell one from the other by (*a*) their axis formation, and (*b*) the number of seed leaves, or *cotyledons*, they have. The axis of the plants of both groups has for its basis a dense cellular structure in the midst of which are the fibrovascular bundles.

Now in plants of the *monocotyledon* group the arrangement of these bundles is *endogenous* (pronounced *en'-do-gen-ous*), which means growing from within, and the fibrovascular bundles are distributed throughout the whole diameter of the axis of the plant without any systematic arrangement. In the dicotyledon group the arrangement of the bundles is known as *exogenous* (pronounced *ex-og"-en-ous*), which means growing from the outside, and if you will examine them you will see that they are arranged side by side quite systematically around the axis so as to form concentric circles of *pith*, *wood* and *bark*.

The Structure of the Leaves.—The structure of the leaves in the higher plants is also very interesting and, moreover, these are easy to

examine with your microscope. The softer parts of the leaves are protected by a distinct membrane which is called the epiderm; this is composed of layers of flattened cells built up one upon the other; the outer layer is the hardest and is called the cuticle.

The epiderm contains little, if any, chlorophyll, or green coloring matter, and is perforated by numerous tiny openings called *stomata*[7]; these run into the tens of thousands to the square inch in some plants. These stomata are usually found on the under surface of the leaves, and it is by means of them that the plant is able to absorb, or breath in, the *carbon dioxide* needed to change its cellular contents into nutritive starch, and exhale, or breathe out, the *oxygen* which is set free by this process.

The interior tissues of the leaf are formed of soft, thin-walled cells, which contain large amounts of chlorophyll.

The Structure of Flowers.—All of the higher plants produce flowers of some kind and you should at least know the principal parts of which the typical, or normal, flower is formed. There are four chief parts to a flower: (1) the *calyx,* (2) the *corolla,* (3) the *stamen,* and (4) the *pistil.*

The *calyx* is the outside envelope of the flower which is usually formed of a ring of

[7] Plural of *stoma,* which means *pore.*

green leaves known as the *sepals,* the purpose of which is to protect and support the more delicate and colored leaves of the flower, or *petals,* as they are called. This brilliantly colored circlet of leaves makes up the *corolla.* The calyx and corolla together serve as a protection for the extremely delicate reproductive organ which they inclose.

The *stamen* of the flower is composed of the *filament* and the *anther;* the filament is the threadlike part which supports the anther at its top and contains the *pollen,* or the male fertilizing element. The *pistil,* which is found in the center of the flower, contains the ovary, or female organ of reproduction, and this incloses the ovules (the female elements); the latter after being fertilized by the pollen develop into the seeds.

The Structure of the Seeds.—In the seed is developed the embryo plant, and enough nourishment is stored within the former to nourish the latter until it gets its start in life as a growing plant by forcing out its roots into the soil. As I have already mentioned, the seeds of the higher order of plants are always inclosed in pods or in a fruit. As a rule the bursting of the pod or the rotting of the fruit after it has fallen to the ground liberates the seed.

The side walls of the cells of some seeds are made thicker and are provided with membran-

ous *wings* which extend out on either side of the seed. If you will examine these wings closely under a high power with your microscope, you will find that they are formed by the lengthening out of the cells which coat the seed proper; those which form the ribs to support the wings are thickened and opaque while those which form the membranous surface retain their original transparency.

While it is not possible to go into a more detailed description of the structure of plants in this book, you will, with the outline which I have given above, be able to discover for yourself a thousand and one other wonderful things about them.

CHAPTER X

LOWEST FORMS OF ANIMAL SPECIMENS UNDER THE MICROSCOPE

After you have examined the forms of plant life described in the foregoing chapter you are ready to take up the study of animal life. The chief difference between plant life and animal life is that animals have the power of *self-locomotion,* that is, the ability to move about of their own accord, while plants only rarely possess this attribute.

Further, the whole animal kingdom may be divided, for the purpose of identification, into two general classes: (1) *Protozoa,* and (2) *Metazoa.* These classes can be told from each other by (*a*) the kind of cell structure of which the animal is built, that is, whether it is *unicellular,* which means that it is formed of a single cell, or an aggregate of single cells, each of which can keep up an independent existence; or (*b*) whether it is *multicellular,* which means that it is composed of many cells having different functions, each cell contributing to the life of the organism as a whole and being unable to exist alone for any length of time.

All the *Protozoa* are *unicellular* animals while all of the *Metazoa* are *multicellular*. This latter class contains by far the largest number of species, besides including all of those animals with which we are most familiar.

The Protozoa, or Single-Celled Animals.—*Protozoa,* which are unicellular animals, are divided into four groups: (1) *Rhizopoda,* (2) *Mastigophora,* (3) *Sporozoa,* and (4) *Infusoria.*

The Rhizopoda.—These minute animals are unicellular and have a definite *nucleus* and *cell wall.* The name *rhizopod* means *root-footed,* and they are so called because they have root-like processes, which they are able to thrust out at will from any part of their bodies. These are called *pseudopodia,* or *false feet,* since *pseudo* means *false* and *poda* means *feet.*

Not all of the members of this group, however, have these rootlike pseudopods, but instead are of what is called a *lobate* nature, that is, they have irregular projections extending from their bodies and these are constantly undergoing a change in form, number and position. Members of this group are called *lobosa,* and, since they are the most common animal found in every pond and stream, I shall describe one of them as a type and this is the *Amœba.*

The *amœba* is a rhizopodic protozoan which you will see under a high power, and is made

up of the following parts: (1) an *ectosarc,* (2) an *endosarc,* (3) a *nucleus,* (4) a *contractile vacuole,* (5) *lobate projections,* and (6) *food vacuoles,* all of which are shown in Figure 39. The *ectosarc,* which means *inside flesh,* and the *endosarc,* which means *outside flesh,* are formed of cytoplasm; the ectosarc forms a membranous envelope, or skin, which incloses the endosarc, or inside flesh. The nucleus, as

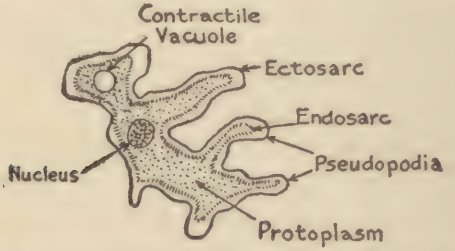

FIG. 39.—THE AMOEBA—A UNICELLED ANIMAL

in the algae, is the life center of the cell, and the contractile vacuole is the means by which waste gases and fluids are removed. The food vacuoles engulf the minute food particles which are then digested providing the body with nourishment. The lobate projections are formed by an extension of the ectosarc and endosarc and the *amœba* moves about from place to place by means of these fingerlike extensions into which the substance of the body is transferred.

Like the *algae,* the *amœba* multiplies by the process of simple division of its cells. Under

the microscope you will sometimes observe that one of the lobate projections becomes enlarged and fixed at the extremity, and the neck connecting it to the body will contract or thin away, until the lobe separates entirely from the latter. The detached part then becomes an independent *amœba.*

The Sporozoa.—These are protozoan animals which are characterized by the manner in which they reproduce. They are parasitic animals found in the intestinal canal of insects, worms and the higher animals and they reproduce their kind as follows: the body of the animal takes on a globular form and becomes *encysted,* that is, covered by an envelope, or *cyst.* The nucleus next disappears, and the substance, or protoplasm, in the cyst breaks up into particles which are called spores, spherical or oval forms. The cyst then bursts and the spores escape, and, after passing through an *amœboid*[1] stage, finally develop into adult *Sporozoa.*

Mastigophora and Infusoria.—These protozoans have more or less fixed cell walls, and possess a few or many cilia, which are used in locomotion. They may travel at great speed when seen under the microscope, and unless you use some glycerin jelly or other harmless material which will slow them down, you won't

[1] That is like an amœba.

make out much about their structure. They may be found in stagnant water where there is considerable decaying plant matter. The animals possess the same structures as were described for the amœba.

The Metazoa, or Multicelled Animals.—Next higher in the scale of animal life are those which have a *multicellular* structure, or *Metazoa,* as this great division is called. In animals of this kind the egg cell divides and the cells that result from this process combine so as to form an organic whole, or life unit, and the various groups of cells then perform the different functions for the animal; or, to put it another way, the cell groups are developed into *organs.*

The Porifera.—The most simple of the *Metazoan* animals are the *Porifera,* or *sponges,* as they are commonly called. Now the sponge you buy in the drug store and the sponge as a living animal are two very different things, for in the first what you see is only the *horny skeleton* which is formed of a substance called *Spongin*—an organic material, and this is often strengthened by mineral deposits; hence it is entirely without life.

In life the sponge consists of this skeleton, or framework, upon which are two layers of cells which form a system of canals and cavities. These passages are lined with fine, hair-

like processes, or *flagella,* as they are called, and move constantly back and forth. The movement of the flagella sets up currents of water in the canals and cavities, the incoming currents drawing the necessary food and oxygen into the sponge while the outgoing currents carry off the waste matter through the *oscula,*[2] or exhalant pores, as shown in Figure 40.

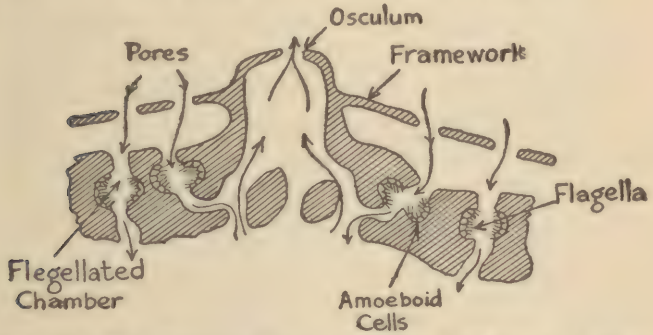

FIG. 40.—THE STRUCTURE OF A SPONGE—A SAC-LIKE ANIMAL

Sponges reproduce themselves in two different ways: (1) nonsexual, and (2) sexual. In the first way spores are formed within the flagellate chambers which are set free through the oscula, and this lays the foundation for a new colony of sponges. In the second way certain cells of the sponge are transformed into *sperm cells* and these develop *spermatozoa*—the male cells. Other cells, known as *egg cells,* and which are the female cells, after being fertilized by the

[2] Plural of osculum.

sperm cells, develop into *ciliated cells*, that is, cells having hairlike processes, and by means of these they are able to swim out of the oscula in the parent sponge and begin life for themselves. Later these grow into sponges like the parent from which they come.

The Coelenterata, or Zoöphytes.—We now come to a group of animals that, while a little higher in the scale than the sponge is more or less plantlike, the *Coelenterata* (pronounced *Cel-en"-ter-a'-ta*) or *Zoöphytes*. While these are *Metazoic* animals, that is, multicellular, at the same time they are peculiar in that some of the cells which go to make up the animal keep, to a large extent, their independence.

This is shown by the fact that, while the animal has a multicellular organ called a *digestive sac*, the individual cells which line this sac are really the means by which food is taken into the body. A further evidence of the property of protozoic independence maintained by the cells is the property of the animal to reproduce itself from a minute portion of any part of it. This phylum of animals can be divided into three classes: (1) the *Hydrozoa*, (2) the *Scyphozoa* and (3) the *Anthozoa*.

The Hydrozoa or Polyps.—To this family belongs the *fresh* water *Hydra*, a very common kind and one which is found in nearly every fresh-water pool and pond. The body of this

little animal is a sac usually consisting of a long, slender cylinder, having at its upper end an opening, or mouth, which is surrounded by numerous arms, or *tentacles,* as shown in Figure 41, which are covered with wartlike protuberances, called *nematocysts.*

In the center of each of these is a dart, and when the Hydra wraps its tentacles around the living body of some minute water animal, the dart is projected into its body when it quickly dies because of some poison poured out from the nematocyst. In this way Hydra gathers in its food, the long arms taking it to its mouth which opens directly into the body sac, or the so-called *stomach.* At the base of its body is a suctorial disk and by means of this the Hydra attaches itself to the leaves and stems of water plants. Like the sponge the Hydra reproduces itself by both sexual and nonsexual means.

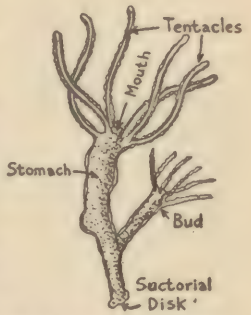

FIG. 41.—THE HYDRA—A PLANTLIKE ANIMAL

The Scyphozoa, or Jelly-fishes.—The animals in this class are nearly always free-swimming, and are shaped very much like a bell. In these two ways they differ strikingly from the *Hydrozoa,* but in other respects the two are similar.

The *Scyphozoa* possess the stinging cells, many tentacles, and a stomachlike sac in which food is digested. Some of them may grow very large as for example, the Japanese man-of-war, a common form in the Gulf stream. They reproduce by means of sperms and eggs, the usual sexual method.

The Anthozoa, or Sea Anemones and Corals.—These marine animals grow in colonies, and the soft tissues of the individual members of a colony are held together by means of a mineral deposit with the result that a rocklike mass is formed. The latter contains numerous circular cells in which there are vertical partitions, or *Lamellae,* as they are called, and these make the stomach and the rest of the organs lie in separate chambers.

Now the structures of the animals which I have told you about up to this time are more or less simple from a zoölogical standpoint, but with animals from now on which are higher in the scale of life than the *zoöphytes,* the structures rapidly become more and more complex. Since this is the case I can give you only a brief description of the main phyla, but in so doing I shall point out those features of the structures which are the most interesting when examined under the microscope.

The Echinodermata, or Sea Urchins and Starfish.—The first of these higher animals are the

sea urchins and *starfish,* or *Echinodermata* (pronounced E-chi'-no-der'-ma-ta) as they are known. Like the *Anthozoa* described above, these animals have a *calcareous* skeleton, that is, one composed of *calcium carbonate,* or *limestone,* as it is commonly called.

The skeleton generally consists of a number of layers of calcium carbonate, superimposed one on the other and joined together by short ribs of the same material; the openings of one layer are so placed that they come over the solid portions of the layer under it and form a kind of a network.

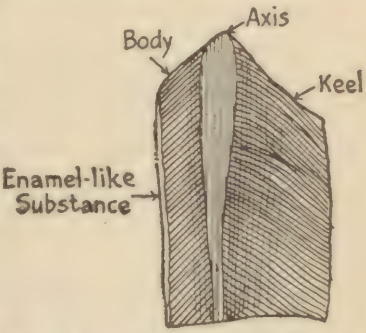

FIG. 42.—A TOOTH OF ECHINUS

Animals of this order are further provided with teeth which your microscope will show to have a structure very like that of the skeleton and a shape very like that of the front teeth of rodents, that is, animals of the gnawing type, with the exception that these teeth are reinforced on both sides by short rods of calcium carbonate, and these set into the main part of the tooth as shown in Figure 42. The teeth themselves are set in jaws, or plates, whose structure is identical with that of the skeleton.

Members of this order show what is called *radial symmetry,* which means that the various parts of their structure are arranged and radiate from a common starting point like the spokes of a wheel from the hub. The very young stages of the *Echinodermata* are *larvae*[3] which have bilateral symmetry, that is, two sides are symmetrical with a *ciliated*[4] fringe arranged around them. The embryo is unlike the parent in many respects, but later resembles it, and as growth takes place the substance of the parts of the embryo which are not needed in the parent is used to feed the growing embryo.

The Vermes, or Worms.—Next in order of complexity of structure is the subkingdom of animals whose scientific name is *Vermes,* but which are commonly known as *worms.* There are three phylo of worms: (1) the *Platyhelminthes,* (2) the *Nemathelminthes,* and (3) the *Annelida.*

The Platyhelminthes, or *flat worms.*—This is the scientific name that is given to all worms which are flat and not segmented, many of which are parasitic within the bodies of other living animals; one of these parasites is the *Tapeworm,* classified under the head of *Cestoda.* They are often found in the intestinal

[3] The maggotlike young of insects.

[4] That is, hairlike.

passages of both man and beast and grow to great length.

These worms live by absorbing the juices produced within these organs. The common tapeworm has no mouth or stomach and each segment of which the body is composed contains its own reproductive organs, the male and female, which are combined so that each segment can produce its own eggs independent of the other segments. The segments are usually connected by two pairs of canals running lengthwise which seem to form a sort of *vascular* system.

The Turbellaria.—This is another order of flat worms that is characterized by *cilia,* or fine hairlike processes, which cover the entire surface of the body. These worms are found in both fresh and salt water and therefore are quite common. In general the body is rather long, having a flattened, solelike shape, and is provided with a *suctorial*[5] mouth so that it can attach itself to its prey and draw out its nourishment.

The mouth opens into a short tube, the *esophagus,* which in turn opens directly into the cavity of the stomach. The stomach is very curious, for from it a large number of canals extend so that they reach every part of the body as shown in Figure 43. In this way the ani-

[5] That is, a sucking mouth.

mal lives without a true circulatory system, since the canals serve as a circulatory and *gastro-vascular* system at one and the same time.

These animals sometimes reproduce by sexual means, but usually they split down the middle when each segment so formed becomes

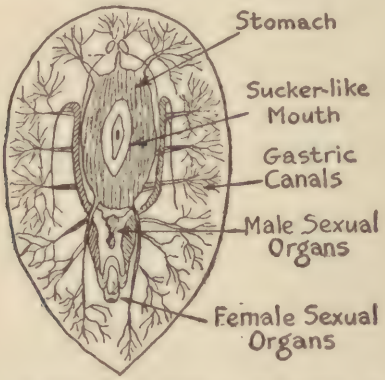

FIG. 43.—A LONGITUDINAL SECTION OF WORM OF THE CLASS TURBELLARIA

an individual animal, and may, in turn, divide in like manner. In the light of their ability to reproduce from a small part of the body, the *Turbellaria* are very like the *Hydra* about which I told you before, although their general structure is of a much higher nature.

The Nemathelminthes or *round worms.*—These worms can easily be distinguished from the Platyhelminthes, because they are cylindrical in shape, tapering at both ends. Some

of them live freely in the soil and water everywhere, and some are parasitic, living within the bodies of other animals. You may be almost sure of finding some if you examine most any foul, stagnant water, or look within the intestines of frogs, cats, dogs, horses, etc. One of the worst enemies of the farmer is a round worm, whose name is *Ascaris*, and which lives in the intestines of all domestic animals and sometimes of man. If the hosts are not properly cared for, this little round worm will kill a whole herd of animals. Another important one is *Necator*, which causes the terrible hookworm disease. You will find it very easy to examine members of this phylum by getting some *Anguillulidoe* (pronounced *An"-guil-lu-li'-dea*) which are little eel-like worms. *Anguillulea glutinous* is the name given to that particular kind known as *paste eels* which develops in sour paste. These eels are often found in vinegar, when they are called *vinegar eels*, or to give them their scientific name *Anguillulea acetic*. If you will examine these eels under your microscope you will be entertained with a very remarkable spectacle.

The Annelida.—Members of this phylum include those worms which are highest in the scale of their kind and which show well-defined segments, and are for the most part *elongated*, that is, long in shape. In some worms, as the

leeches, the division into segments is not so well defined. Upon the outside shape of the *Annelid worms* depends the kind of respiratory appendages they have.

In the *Tubiculous* forms, which have a hard, shell-like outer skin that incloses the softer tissues of their bodies, the respiratory organs, through which the fluids of the body are sent for *aëration,*[6] are located on the head, while in the *non-Tubiculous* species which can swim about freely or crawl, since they do not have a shell-like skin, the respiratory organs are located on the sides of the animal. In this latter species, which are *carnivorous,* that is, meat eating, the mouth is horny, or *armored,* as it is called, and is provided with strong teeth and jaws.

Under the microscope you will plainly be able to see the circulation of the fluid in these respiratory appendages. The fluid is of two kinds, the first being a colorless one which contains cell-like corpuscles, and is found in the space between the alimentary canal and the inner wall of the worm's body. You will see that it passes into canals which enter the respiratory organs but that no return system is provided. Another fluid that is red will be seen; this is carried along by a system of vessels in the body, propelled by a *dorsal*[7] *vessel.*

[6] To be exposed to the air for purification.

[7] Dorsal means situated near the back.

This latter organ acts as a respiratory heart and drives the fluid through the respiratory vessels and then is directed back again.

The *Annelids* are *oviparous,* which means that they produce eggs. The embryo comes forth from the egg in a very undeveloped condition and consists of a mass of cells; some parts are provided with *cilia.* Shortly after emerging from the egg, this mass becomes elongated and the appearance of segments is shown more or less clearly by rings. Finally the various internal organs begin to shape themselves into segments, and eventually all of the organs and appendages are produced that are found in the adult.

CHAPTER XI

HIGHER FORMS OF ANIMAL SPECIMENS UNDER THE MICROSCOPE

By this time you have gathered that the further you get along your work with the living animals, the more complex the structures of their bodies become, and it follows, to some extent, the larger the animal becomes, although this does not always hold good. The next higher class of animals is commonly known as *shellfish* which are scientifically called, *Mollusca.* The *Mollusca,* which include the oyster, clam, cuttlefish, snail and slug, are a step higher in the scale of life, than the worms.

There are three kinds of these animals: (1) those that have a *two piece,* or *bivalve shell;* (2) those that have a *one piece,* or *univalve shell;* and (3) those that are *naked,* or have no shell at all. The class called *Gastropoda* includes those that are univalve. This class has a very curious structure of the tongue, or palate, and the development of its embryo, which will be described presently, is also interesting.

The Mollusca.—The structure of the shells of *molluscs* is of much interest under the microscope. Usually the shell will be found to be made up of three separate layers of *calcareous*[1] matter. The outer layer is very thin and often rough and of a brownish, or dark gray, color, the middle layer is much thicker and dull white; while the inner layer is usually pearl-like in color.

If you will examine a section of the middle layer you will find that it has a honeycomb appearance and is made up of a large number of *prismatic*[2] cells which are hexagonal, that is, six-sided, in shape. This structure is deposited by the outer skin, or *epidermis,* that has been given its crystalline form by successive deposits of *calcium carbonate* inside the cells of which it is composed.

The inner layer of the ordinary shell is known as *mother-of-pearl,* or nacreous layer, it has an irridescent luster which is caused by the peculiar texture of the surface due to the numerous surface layers, or laminae.[3] In the pearl oyster, or to give it its scientific name, *Meleagrina Margaritifera,* the pearl is formed as follows: a particle of foreign matter, such as a grain of sand, gets into the shell and acts as an

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1 Made of *calcium carbonate,* that is, limestone.

2 Having the colors of the rainbow.

3 Plural of *lamina.*

irritant to the oyster. A layer of *nacreous* matter, like the inside layer of its shell, then begins to form, or *concrete* around the foreign matter, and in this way the pearl is built up layer on layer.

The *Gastropods* belong to the family of molluscs and include the *snails* and *slugs*. The tongue, or palate, of a *Gastropod* is a wonderful object under the microscope, and while it is called a *tongue* it is unlike that of any other animal. It consists of a short tube which is split open at its upper end and spread out on the floor of its mouth; the inside of this tube is studded with teeth, as shown in Figure 44, and these range in number from 100 to 20,000 according to the species.

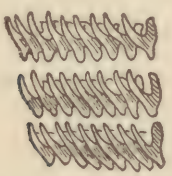

FIG. 44.—ARRANGEMENT OF TEETH IN THE PALATE OF A GASTROPOD

In some *Gastropods* such as the whelk,[4] which has a whorled shell, that part of the toothed tube which rests on the floor of its mouth is provided with *protractile*[5] and *retractile*[6] muscles, and these enable it to be used as a drill with which the whelk bores through the hard shells of the other molluscs it feeds upon.

[4] A gastropod which burrows in the sand and preys on clams and other bivalves.

[5] Muscles which extend or push out something.

[6] Muscles which pull in.

A peculiarity of this arrangement is that the teeth can also be raised or lowered at will, and as fast as the old teeth are worn out they are replaced by new ones.

More interesting yet is the development of the *embryo*[7] of the *Gastropods* which lay the eggs from which the embryo is hatched. In some species, such as the *seaslug,* the number of these eggs is upwards of a half million, they are very small when first laid. As the eggs are quite transparent you can easily watch the changes that take place in the formation of the embryo in them. These eggs are deposited in masses and are distributed throughout a jelly-like substance which is found attached to the surface of the various seaweeds and polyps.

The first change to take place inside the egg after fertilization is the splitting, or *segmentation* as it is called, of the material so that there are two equal cells, just as the *Amœba* undergoes subdivision. Each of these in turn divides into two more cells and this process is carried on until a very large number of cells is produced, all of them remaining together in an irregular mass. Finally, a two-layered hollow structure results which is the *Gastrula,* and in time each one of these becomes an embryo, when the latter puts out a *cilia Fringed lobe* on either side of its *anterior,* or front end. About

[7] The germ, or earliest development of a rudimentary animal.

this time the rudimentary organs of hearing, or *auditory vesicles,* as they are called, are formed but do not develope any farther.

An extension also grows out from the embryo

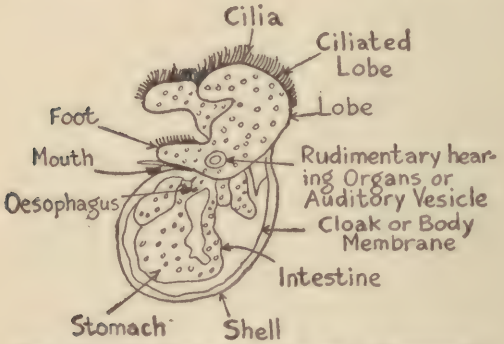

FIG. 45.—EMBRYONIC STAGE OF A GASTROPOD

which in time becomes a *muscular disk,* or foot, and by means of this the adult can attach itself to rocks, etc. Next a shell gradually forms on and around the embryo, and soon after the egg case bursts and the embryo swims freely around by means of the *ciliated lobes* which serve to bring food to its mouth, as shown in Figure 45; later on these ciliated lobes disappear and the toothed tongue, or palate, begins to develop.

You will also like to know about the *pigment cells,* or *chromatophores,* that are found in members of the *cuttlefish* and *squid* family; it is by means of these cells that the animal can change its color at will. They consist of cells

containing various particles of color, including some that are inky black, called *melanophores,* these are so made that they can take on either a globular, or a flattened and elongated form; in this way the density, or depth of color, can be changed.

The Division of Arthropoda.—One of the largest phyla of the animal kingdom is named *Arthropoda;* it contains one order—the insects, or *Insecta*—of which there are probably over a million distinct species, although less than half of this number has been classified. You ought to be able to know the four general classes of *Arthropoda* when you see them; (1) the *Arachnida,* which includes the spiders; (2) the *Crustacea,* which includes the crabs; (3) the *Myriapoda,* which includes the thousand-legged worms, and (4) the *Insecta,* which includes flies, etc.

The members of the *Arthropoda* division may be described in a few words as being *articulated animals,* by which I mean that they are made up of a number of segments, which in the typical *Arthropoda* are limited to twenty or less. They are *bilaterally symmetrical,* since to these segments are attached pairs of jointed appendages that are alike on both sides. These segments are called *somites* and are hard, shell-like rings, or hoops, which are joined to each other by softer membranous tissues. The appendages consist as a rule of (*a*) from one to

two pairs of feelers, called *antennae*; (*b*) from two to four pairs of *jaws;* and (*c*) upwards of three pairs of jointed, or articulated, legs. It is also interesting to note that (*d*) the eyes range from one to four pairs and that these are *simple* in spiders and *compound* in crabs and insects.

The Arachnida, or Scorpions, Spiders, Ticks and Mites.—These *Arthropoda* have no antennae and a body that is made up of two parts only, namely (*a*) the *cephalothorax,*[8] and (*b*) the *abdomen.* They usually have six pairs of jointed appendages, two pairs of which are fixed to the head and serve to catch and hold their prey, while the other four pairs serve as legs.

Most of these animals breathe by means of *trachae,* or air tubes, and takes in the necessary air through *spiracles,* or breathing pores in the body. The Arachnida are divided into ten orders of which the following are the most important: (1) *Scorpionidae,* or scorpions; (2) *Araneida,* or spiders; and (3) *Acarina,* or mites and ticks.

The Crustacea, or Crabs, Lobsters and Shrimps.—The members of this division are very like that of the *Arachnida* in that the body is composed of only two parts, that is, the cephalothorax and the abdomen. Their characteristic feature is the protective shell, or *carapace,*

[8] This means a united head and thorax.

as it is called, with which they are covered and which is secreted by the skin and impregnated with *calcium carbonate* deposits.

In most of the orders of *Crustacea* this shell consists of segments and forms a protective coating over the appendages as well as over the body proper. There are two main divisions of *Crustacea* that you should get clear in your mind: (1) *Entomostraca,* which include the smaller and more lowly organized forms, such as *water fleas* and *barnacles;* and (2) *Malacostraca,* which include the larger and more highly organized forms, such as the *lobster, crab, shrimp* and *crayfish.*

Myriopoda, or Millepeds.—These curious jointed animals are known by their long worm-like bodies which, usually, have some of the segments fused together and have a length of from two to 18 inches. Each segment has one or two pairs of appendages attached to it and as the segments number from 10 to 50 you can easily guess how these many-legged animals come to be called *millepeds.*

There are four orders of *Myriopoda,* the two important ones being (1) the *Chilopoda,* or *thousand-legged worms;* and (2) *Symphyla,* or *centipedes.* You can easily tell them apart because, as I mentioned above, the first has two pairs of legs attached to each segment and the latter only one pair to a segment. It is in this

latter order that the poisonous kind is found, the first pair of legs being fused at the base so as to form a poison sac.

The Insecta, or Insects.—Finally there is the great class of *Arthropoda* known as *Insecta;* this includes all the true insects. The members of it are characterized by having three separate and distinct body parts: (1) a *head;* (2) a *thorax* or middle part; and (3) an *abdomen,* or that part containing the digestive organs. There are, moreover, attached to the thorax one or two pairs of wings in the *winged* order and three pairs of legs.

If you will examine the head of a typical insect you will find that there are four pairs of jointed appendages, namely, the *antennae,* and the mouth parts, or *mandibles* and *maxillae,* as they are called. An examination of the thorax will show that the segments are usually fused together where the wings are joined on to hold the powerful wing muscles. The body is provided with spiracles, and the insect breathes through these and the trachea. The true insects are fitted with compound eyes which will be described presently.

Since there are upward of a million species of insects their classification is bound to be more or less complicated, but it is based on two well-defined features which are distinctive in the larger number of species, namely,

whether the insect is (*a*) *wingless,* or (*b*) *winged.* The first kind is known as *Apterygota* and the second as *Pterygota* (pronounced *Ter-i-go-ta*).

The *Apterygota,* or wingless insects, include two suborders which are (1) *Thysanura,* or *bristletails,* and which are often called *fishmoths* owing to their resemblance to moths; and (2) *Collembola,* or springtails, owing to the very curious springlike caudal appendage which they have.

The *Pterygota* is further subdivided so that members of it can be identified into two kinds: (*a*) *Heterometabolous,* or insects whose young, or *nymphs,* as they are called, pass through a very slight *metamorphosis*[9] or none at all; and (*b*) *Holometabolous,* or insects whose young go through a complete metamorphosis.

The Parts of an Insect—*The Integument.*—Now suppose you look a little closer into the structure of insects; this is easy to do because you can get all the specimens you want right at hand. In dissecting any typical insect so that you can examine it under the microscope, you will see that its body is covered with a sort of hardened skin, or *integument.* This horny casing is composed of an animal substance known as *chitin* which may be strengthened by deposits of mineral matter.

[9] Passing of one form or shape into another.

The Appendages and Other Structures.—Insects are provided with numerous interesting structures, such as (1) the *scales,* or *plates,* (2) the *hairs,* (3) the *antennae,* and (4) the *legs* and *feet.* Scales are found on both surfaces of the wings of many insects, particularly in those of the moth and butterfly tribes.

These scales are often brilliantly colored, and in moths and butterflies this color is due to the structure of the scale which is made up of two or more layers of membrance with a layer of pigment between them. In beetles, however, the color of the scales is due to the extreme thinness of the membrane-layers, which reflect light just as the film of a soap bubble does.

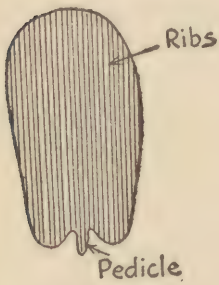

FIG. 46.—THE SCALE OF A BUTTERFLY

Many insects and their young, one stage of which is the *larva,* are covered with *hairs* as, for instance, the bee and the caterpillar. These hairs are usually formed, as you will clearly see with your microscope, of (*a*) a long rodlike shaft around which (*b*) spiny whorls are set. Mounted on the tip of the whorl is a circle consisting of six or seven large filaments which are knobbed at their free ends, the smaller end being attached to the tip of the hair.

Nearly all insects have *antennae,* or feelers; these consist of one or two pairs of jointed appendages which start from the upper part of the head. These feelers differ greatly in various species, and are sometimes unlike even in the male and female of the same species, and hence they are very useful as a means of classification. If you examine the feelers closely, you will find inside the horny integument of many species a complete set of organs by means of which the insects are believed to be able to hear.

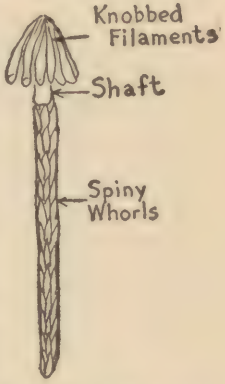

FIG. 47.—HAIR OF A BEETLE UNDER THE MICROSCOPE

The legs and feet of the insects are also very interesting microscopic objects. The leg, as a rule, consist of five segments, the feet are provided with hooked claws and, in most insects, with adhesive pads by means of which they adhere to the objects they happen to light on.

The Head Parts.—Next examine the head parts. These are wonderfully made. The eyes are located in the upper part of the head and are *compound,* that is, they are made up of hundreds, and in some species thousands, of will find inside the horny integument of many separate little eyes, or *conical acelli,* as they are

termed, each of which is connected to the optic nerve.

The *mouth parts* are another means of classification; insects usually have what is known as a *mandibulate* mouth; this is made up of (*a*) *mandibles,* or main jaws, which are fitted with formidable teeth in some species; (*b*) the *maxillae* which are a second pair of jaws that set just below the mandibles and with which the insect carries the morsel of food to the back of its mouth; (*c*) the *labrum,* or upper lip; and (*d*) the *labium,* or lower lip. The labium is often elongated so that it forms the *tongue* of the bee, and the *proboscis* of the fly.

The Body Parts.—In dissecting the body of an insect you should first of all examine the *esophagus,* which leads from the mouth to what is commonly called the *gizzard.* This organ is lined with several rows of teeth; these reduce the particles of food it eats into a digestible state. The *blood,* which is colorless or brownish red, is kept in circulation by a *dorsal vessel,* which serves as a heart.

The construction of the respiratory apparatus of an insect consists of *tracheæ* or air tubes, as I have described before. Your microscope will show you that these tubes pass into every part of the body, even into such minute parts as the *labium.* The *spiracles* through which the air is drawn into the tracheae are on the

sides of various segments, and are provided with a sort of sievelike membrane over their openings in order to filter the air before it is passed into the trachea system.

In some insects the last two segments of the abdomen are equipped either with (*a*) a *sting*, or (*b*) an *ovipositor*. The sting consists of a pair of darts that are projected from their

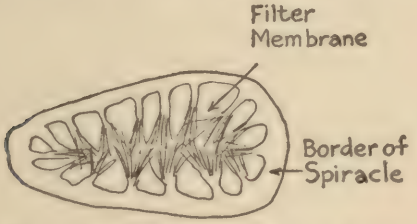

FIG. 48.—THE SPIRACLE OF AN INSECT

sheaths, which latter is formed of an extension of the skin of the last segment, by means of powerful muscles located at their roots. An irritating liquid is secreted at the base of the sting. The *ovipositor* is a device by which some insects deposit their eggs. It is formed of a long tube in which the eggs are carried, and which, like the sting, is sheathed in the last segment. It is also provided with powerful retractile and protractile muscles, and usually has a toothed, or *serrated*, edge so that it can be used as a boring tool, with which it bores a hole to lay its eggs in.

Reproduction of Insects.—In most insects reproduction is carried on in this fashion: the sexual cells of the female are fertilized by those of the male; and these fertilized eggs are laid in some receptive place, where they shortly hatch into *larvae,* which are maggotlike little animals. As these grow larger the skin hardens and forms a protective covering over the body; when in this state the young are known as *pupa.* A complete change in the form, structure and tissues of the pupa takes place, known as *metamorphosis,* during which the young insect is developed in the body of the pupa after which the shell drops off.

CHAPTER XII

HIGHEST FORMS OF ANIMAL SPECIMENS UNDER THE MISCROSCOPE

After you have examined the simpler structures of the lower animals as directed in the foregoing chapters, you will be prepared to take up the great subphylum of the highest type of animals known as the *Vertebrata,* that is, animals with *backbones.*

The Vertebrata, or Animals with Backbones.—This subphylum comprises all the higher animals, including the highest of all, which is *man.* The outstanding features of these animals, which are called *Vertebrates* and which separates them from those we have just examined, is that they have a *backbone;* in the higher orders this forms the main support for the rest of their articulated bony structure, or *skeleton.*

The vertebrate, or backboned, animals differ also from those which are lower in the scale of life in that they are provided with highly complex and well-developed organs which perform all of the functions to maintain life; and

(2) the complex network, or system, of *nerves;* which lead from the brain into all parts of the body and control the various organs. The great subphylum of the *Vertebrata* includes all of those animals that we know best; it has been divided into six chief *classes*: (1) *Cyclostomata,* or lamphreys; (2) the *Pisces,* or true fishes; (3) the *Amphibia,* or frogs, salamanders, etc.; (4) the*Reptilia,* or reptiles; (5) the *Aves,* or birds, and (6) the *Mammalia,* or mammals.

These classes are further divided into numerous orders, and each of these again into *families, genera* and *species.* Now let us take a brief look at each one of the classes above named and find out what their main order are and perhaps a few of their distinctive features.

The Cyclostomata, or Lamphreys and Hags.—These are the lowest of the vertebrate animals and, indeed, they do not even have the true backbone of the higher animals, but instead a mere rod of cartilage,[1] the skull itself being of a *cartilaginous* nature rather than a bony structure; this is also true of some fishes, such as the *sturgeon,* of which they are the forerunner.

The Pisces, or Fishes.—This class is divided into two groups; (1) the *Chondropterygii* (pro-

[1] A semi-transparent elastic tissue that forms most of the skeleton of embryos and the very young of the backboned animals which in the higher animals changes into bone. It is commonly called *gristle.*

nounced *Kon-drop'-ter-y"-i-i*) which are fishes with *soft skeletons;* and (2) *Teleostomi* (pronounced *Tel-e-os'-to-me"*) which are fishes with hard skeletons; of the latter there are about 10,000 species, including all the well-known kinds. All fishes are characterized by their peculiar bony structure, streamlike bodies and gills which peculiarly adapt them to living in the water.

The skeleton of the fish is provided with fins which serve the double purpose of keels and rudders, the *caudal,* or tail fin being the chief rudder. The mouth has long jaws set with teeth. The ribs, which are fixed to the backbone, act as a protective structure for the heart, stomach, intestines and other vital organs, while the breathing apparatus consists of *gills;* these extract the necessary *oxygen* to support life from the water.

The Amphibia, or Frogs, Toads and Salamanders.—This class of backboned animals is just between the reptiles and the fishes. They are characterized by the young having gills which disappear and are supplanted by lungs in the adult of some species. There are three main orders of *amphibia*: (1) the *Apoda,* or *worm-like* animals that have no limbs whatever and which are found in tropical countries; and (2) the *Candata,* or those animals which are long tailed and have two sets of limbs, such as the

salamanders and newts; and (3) *Salientia,* or tailless amphibians which have two sets of limbs, such as frogs and toads.

The Reptilia, or Reptiles.—This class includes not only snakes but other animals which we do not ordinarily think of as reptiles, such as turtles, alligators, crocodiles and lizards. Now there are three chief orders of reptiles; (1) *Testudinata,* or turtles of both the land and sea varieties; (2) *Crocodilini,* or alligators and crocodiles; (3) *Squamata,* or lizards and serpents; all of which lay eggs.

The Aves, or Birds.—Now while we do not usually think of birds as animals they are just as much so as any other living creature, and it is well known that they have been evolved from *reptilelike* animals.[2] There are two subclasses of birds; (1) the *Archaeornithes,* or fossil birds; and (2) the *Neornithes,* or modern birds.

As a matter of fact the *Archaeornithes,* or fossil birds, have no place in this book because you are examining only living animals, or, more strictly speaking, very small sections of living animals where these are of the higher kinds. But because the *Archaeopteryx* (pronounced *'Ar"-ke-op'-ter-ix*) is the sole representative of the true bird that lived in the dim and distant past, and from which was evolved the beauti-

[2] These were the bipedal dinosaurs who walked more or less upright on their hind feet and had a horny bill, or beak.

ful plumed and singing birds of to-day, I cannot help but include it here as a matter of general interest and knowledge. This early bird has come down to us as a fossil, or rock-embedded skeleton, which shows that it had *teeth* and a *long tail* like a reptile, but it also had feathers and could fly.

The *Neornithes,* or modern birds, are short-tailed animals and have no teeth. There are two subdivisions of them, namely, (1) the *Ratitae,* or *running birds;* and (2) the *Carinatae,* or *flying birds.* The first named include the ostriches, ernes and rheas. The distinctive feature of these birds is found in the *breastbone,* or *sternum,* as it is called, which has no keel, and as a consequence there is no place for well-developed wing muscles. The last named include all the living species that fly and of these there are over 13,000. Different from the *Ratitae* they have a well-developed keel which in the flesh is filled out with powerful wing muscles.

The Mammalia, or Mammals.—Finally you have reached that great class of vertebrate animals which are known as *Mammalia,* or, as they are more easily called, mammals. These include not only the largest animals but those whose complex structure places them highest in the scale of animal life. All mammals are provided with mammary glands which secrete a

fluid that we call *milk,* by means of which the young are supplied with nutriment until they are old enough to eat solid foods.

While there are some eighteen separate and distinct orders of mammals, there are only seven that you need to know about; these I have named in the order of their scale of life beginning with the lowest: (1) the *Marsupialia,* or Kangaroo and Tasmanian wolf; (2) *Cetacea,* or whales and porpoises; (3) the *Ungulata,* or hoofed animals; (4) the *Rodentia,* or gnawing animals; (5) the *Chiroptera,* or bats; (6) the *Carnivora,* or beasts of prey; and (7) the *Primates,* or monkeys and apes, and *man.*

The Marsupialia, or Kangaroos and Tasmanian Wolf.—The distinctive feature of these animals is the pouch, or fold of skin on the abdomen, in which they carry their young after the latter are born.

The Cetacea, or Whales and Porpoises.—These animals, you will observe, belong to the order of mammals and not to that of the fishes. They are known by their lack of teeth; are warm-blooded, and suckle their young. Like the fishes, however, they have streamlike forms and live in the water.

The Ungulata, or Hoofed Animals.—In this order are included all the true hoofed animals; they have from two to five toes coated with a thick horny skin, or epidermis. The Ungulates

are subdivided into groups which have (*a*) an *even* number of toes, and (*b*) an *odd* number of toes.

The latter have four-chambered stomachs and can swallow their food without chewing it; it passes into the first two of these chambers; here it is softened; then it can be returned to the animal's mouth for mastication, that is, chewed, at leisure. This process is called *ruminating*. Deer, cattle and all animals that "chew the cud" are known as *ruminants*.

The Rodentia, or Gnawing Animals.—These are mammals such as the beaver, rabbit, rats and mice, and all are characterized by their sharp, chisel-like front teeth which are adapted for gnawing. This is the largest known order of mammals and includes twenty or more families and several thousand species.

The Chiroptera, or Bats.—The bats are the only order of mammals that have the power of flight. They have wings formed of thin membranous tissue and are almost as much at home in the air as the birds are. It is a prevalent notion that bats are blind, but they have very good eyes and exceptionally good ears.

The Carnivora, or Beasts of Prey.—To this great order belong such mammals as cats, dogs and all other hunting and meat-eating animals, or animals that are *carnivorous*, as they are called. They are distinguished by their teeth,

strength, litheness, and the mechanism of their claws, all of which are suited to their preying instincts.

The Primates, or Monkeys, Apes and Man.—These mammals are the highest in the scale of animal life and all of them are very much alike in their general structure. The accepted theory of the evolution of *man,* the highest primate of all, is that he came from an ancestor that was common alike to him and monkeys and apes. In this connection it is interesting to note that *man* who originated in the Old World and all Old World monkeys have 32 teeth. Like *man* the monkeys require nearly a year to produce their young, and the female of the species produce but one or two offspring at a time.

The Structures of the Higher Animals.—Having now a general idea of the different subdivisions of vertebrated, or backboned, animals you are ready to take up the various structures of their many parts; to do this you must dissect them and mount the minute sections so that you can examine them with your microscope.

The Cells and Fibrous Structures.—All of the higher animals, including *man* are built up of two kinds of structures, (1) *cellular tissue,*[3] and (2) *noncellular,* or *formed material.*

[3] By tissue is meant an aggregate of cells, together with the substance that is in between them which form one of the materials of which a plant or animal is constructed.

The *cellular tissue* consists of cells which are able to transform materials taken from the blood of the animal into the same material of which are composed, or into a product which they can further expand. In other words, these cells make up the living and growing units of the body *tissues*.

Now these cells are quite like the cells of the *amœba*[4] in structure and composition; they have a definite cell wall that incloses the contents of the cell, which is protoplasm; they contain a *nucleus* which plays an important part in the building-up, or *formative* power, as it is called. The *fatty tissues, muscular tissues, nervous tissues, connective tissues* are illustrations.

The development of the cells, or the multiplication of them, takes place by means of subdivision in much the same way that has already been described in connection with lower plant and animal organisms.

The *formed material* mentioned above, such as the *fibrous*[5] tissues of the body, is incapable of increasing itself because it consists of dead *organic* or mere *inorganic*[6] deposits. These fibrous tissues serve to bind the other parts of the body fabric together and the skeleton, or bony structure, is formed of these tissues which

[4] See Chapter IX.

[5] Containing or consisting of fibers.

[6] Any kind of matter that is composed of neither plant nor animal matter.

have been strengthened by calcareous[7] deposits. The bony structures are built up as follows: the cells, called bone cells, which form their basis are connected by extensions which pass between the fibrous tissues and form a network. These radiating canals are pathways for nourishing material, and for nerves in the bony structure; they are further described in the next section.

The Structure of Bone and Teeth.—If you will examine a lengthwise section of a long round bone, or a parallel section of a flat short bone under a low power, you will see that it is traversed by many canals, which are known as Haversian canals, after Havers who discovered them. These canals run in the same direction as the length of the bone and are filled with an oily marrow just as the large central cavity of the bone is; further, you will see that the canals are connected by a network of cross branches.

Now place a cross section of the same bone under a high power and you will see that each of these canals, which look like a little tube, is the center of rings of bony tissue arranged around the Haversian canal. These rings are made distinct by dark oval spots, or *lacunae*,[8] as they are called; these are cavities in the bony structure which contain the bone cells with *tu-*

[7] This means *calcium carbonate*, or *limestone*.
[8] This word means spaces between the cells.

bules that radiate inwardly from them to the Haversian canal, and outwardly from them to circumference of the bony rings; these tubules, which are shown in Figure 49, are called *canaliculi*.[9]

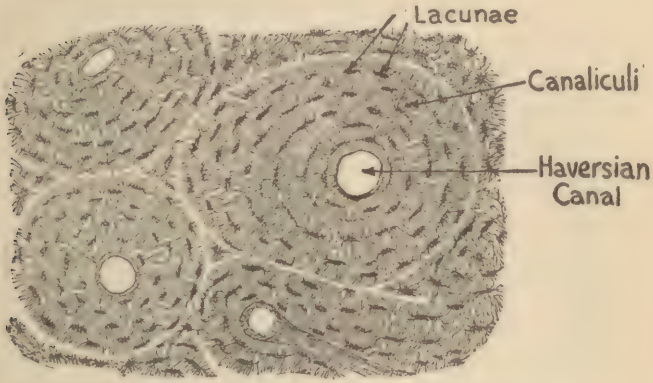

FIG. 49.—A TYPICAL BONE STRUCTURE

The purpose of these canaliculi has already been explained, namely, to keep the bone cells in the *lacunae* in touch with the walls of the surrounding blood vessels from which they get their nourishment. You can tell from the size and shape of the *lacunae* whether the bone belongs to a mammal, a bird, a reptile or a fish, since those of mammals are shorter in length and smaller in breadth than those of birds, and those of reptiles are very long and narrow, while those of fishes are angular in shape.

[9] Evidently meaning little tubes.

The structure of the teeth of the lower vertebrates is very like that of bone which I have just described except that the *canaliculi* do not pass into the *lacunae*. In the higher vertebrates the center of the tooth is a single large cavity from which the *canaliculi* radiate toward the outer surfaces. The upper surface of the tooth is covered with *enamel*, the inner part is composed of *dentine* (see Figure 50), which is a bonelike substance. The enamel is made up of long prisms resembling those of prismatic shell substances found in some of the lower shelled animals.

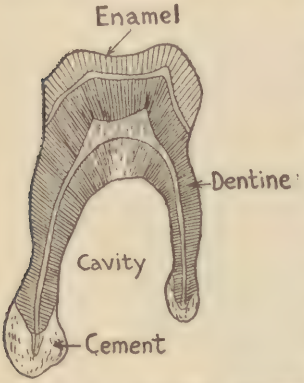

FIG. 50.—A SECTION TAKEN THROUGH A HUMAN MOLAR

The Structure of the Dermal[10] Skeleton.—In a large number of orders, such as *Reptilia* (reptiles) and *Pisces* (fish), and even in some mammals, such as *Armadillo*, the skin is reinforced, or covered, by scales and plates which usually consist of a horny, or bony, texture and in some cases are even enamel-like.

In general, however, these scales, or plates, overlap each other as fish scales do, but they

[10] Of or pertaining to the skin.

are very different from those of reptiles for they are developed in the substance of the skin itself and are *cartilaginous*[11] in texture; further, they are often covered with a layer of epidermis, or true skin. In reptiles, however, the scales are formed on the surface of the true skin and are classed with the other epidermae, or skin, structures of backboned animals. These structures are (1) the *scales and plates of reptiles;* (2) the *hairs of mammals;* (3) the *feathers of birds;* and (4) the *hoofs, nails, claws and horns* of vertebrates in general.

The scales and plates of reptiles are formed on the surface of the skin and are composed of aggregations of greatly flattened cells which, in turn, are built up of horny matter. The hairs of mammals are only a modification of the scale structure just described. If you will examine a hair with your microscope you will see that it consists of two elementary parts which are (1) a *cortical,*[12] or *investing,*[13] substance that is made up of flattened scales in some animals and *spheroidal*[14] cells in others; and (2) a *medullary,* or pithlike, substance which is of a much softer texture than the cortical that surrounds it. This is formed of rounded cells in some cases

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[11] Of or like cartilage.

[12] An external substance.

[13] To cover or envelop.

[14] This means a figure that is like a *sphere,* but which is not spherical, that is, round like a ball.

and *polygonal,* that is, many-sided cells, in others, as shown in Figure 51.

The feathers of birds are really only hairs on an enlarged or slightly more complex scale, the quill corresponding to the bulb, or root, of the hair, and the horny outer part, or barrel of the quill, corresponds to the cortical substance of the hair. The nails, hoofs, claws and horns of mammals are further modifications of the hair structure, for, when a section of any of them is examined under the microscope, you will find it to be made up of a number of little tubes that have the same kind of a cell structure as hairs have when the whole is formed into one piece.

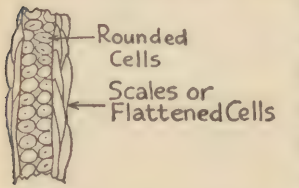

FIG. 51.—A LONGITUDINAL SECTION OF AN ANIMAL HAIR SHOWING STRUCTURE

The Skin.—The next step is to examine the skin of animals, particularly that of mammals. A vertical section of the skin will show under your microscope that it is made up of (1) the *cuticle,* or outer layer of the epidermis; (2) the *perspiratory ducts,* which perforate the outer layer, and also lead into a deep layer, of epidermis, or *Stratum Malpighii,* as it is called, and which separates the epidermis from (3) the *cutis vera,* or true skin in which (4) the

sweat glands are embedded, their ducts leading up through the epidermis.

In the open cavities and canals of the body, such as the mouth and nose, the skin no longer has a tough cuticle, but instead takes on a membranous form of which there are two kinds, called the *mucous* and *serous* membranes; a thin protective fluid which is secreted by the glands in them is spread over their surface, which keeps them from being irritated and drying up.

Structure of the Glands.—All of the necessary secretions of the body, such as the *bile* of the liver, the *saliva* of the salivary glands, and the nutritive fluid of the mammary glands, by which the young are nourished, are produced by organs which are constructed on one general principle. These glands consist of minute *follicles,* or bags, which are filled with spheroidal cells. These cells as they develop draw into them whatever is in the blood that it is their purpose to secrete, and then discharge it into the cavity of the organ whence it is carried away by ducts or the blood stream.

The Structure of the Muscles.—The muscles of animals are made up of a number of *fasciculi,* which are bundles of fibers that lay side by side and are united by a connective tissue. Your microscope will show that they consist of two

kinds, (1) *striated fibers,* and (2) *nonstriated fibers.*

In the striated kind, the fibers are shaped like flat wavy ribbons with cross lines on them; and are found in those muscles of the body where quickness of movement is needed. The nonstriated muscular fibers are found in the walls of the stomach, intestines and bladder where less rapidity of movement is required; these consist of flattened, twisted ribbons without any cross lines which do not lay parallel with each other as in the striated kind, but are interlaced instead.

The Structure of the Nerves.—The nerve cells of vertebrate animals are of two different kinds: (1) an ordinary cell without any long processes that goes to make up the *ganglionic* centers, and (2) a cell with very long processes which forms the nerve trunks. In their typical form the nerve cells of the ganglion are globular in shape; these cells, however, are often slightly elongated, so as to take on the long form. All nerve cells are made up of fine granular protoplasm, the nucleus being found in the spheroidal part of the cell.

The nerve fibers of which a nerve trunk is made consist of a thin membranous sheath surrounding a thicker soft layer, called the *white substance* of *Schwan,* after the man who discovered it. This is a white protoplasmic sub-

stance intended to protect the innermost part, which is called the *Apis Cylinder.* The latter is the vital part of the nerve fiber. Some of the nerve fibers, however, such as those found in the *olfactory* nerve, that is, the nerve which enables you to sense, or smell, an odor, do not have the white substance, and are called *non-medullated nerve fibers.*

The Blood.—It is the blood of vertebrate animals that furnishes the tissues with the nutriment they need; it is made up of *isolated* floating cells of which there are two kinds: (1) *red corpuscles,* and (2) *white corpuscles.* The red corpuscles are always in the shape of flattened disks in man and other mammals, while in birds, reptiles and fishes they are oval.

These *red corpuscles* consist of flattened cells whose walls are not different from the cell contents, although the *nuclei* are absent in the mammals. They contain *hemoglobin,*[15] the red coloring matter of the blood. There are about five millions (*billions,* if the old system is used) of these red blood corpuscles in a cubic millimeter[16] of human blood, each one of which is about 0.008 mm. in diameter. These red corpuscles have a definite and distinctive size in every order of animal, and even in different

[15] This is composed of hematin and globin.

[16] A millimeter equals about 1/25 of an inch; in other words, 1 inch = 24.4 millimeters. The abbreviation is mm.

species of the same order. The smallest are those of a mammal called the *Javan chevrotain,* which measure only 0.002 mm. in diameter, while the largest belong to the *Proteus,* a member of the frog tribe, and measure 0.063 mm. in diameter.

The *white corpuscles* are much smaller than the red corpuscles (see Figure 52), and are much fewer in number being only 6,000 to the cubic millimeter of blood in *man.* They are usually globular in shape and have a prominent nucleus.

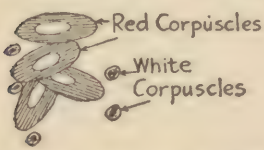

FIG. 52.—HOW THE WHITE AND RED CORPUSCLES IN THE BLOOD OF A FROG LOOK

The Circulation of the Blood.—One of the most interesting and instructive things that you can do with your microscope is to watch the circulation of the blood of some living animal as it courses through the capillary blood vessels, by means of which it is distributed to the tissues which derive their nourishment from it.

A frog is a good animal for this purpose, and you should have a *frog board.* This consists of a piece of wood ½ inch thick, 2½ inches wide and 8 inches long, with a hole ½ an inch in diameter in the middle and about 1½ inches from one end, as shown at *A* in Figure 53. Now take your live frog, wrap him in a strip of wet

muslin, then lay him on his back on the board and keep him there with a couple of rubber bands slipped around him and the board.

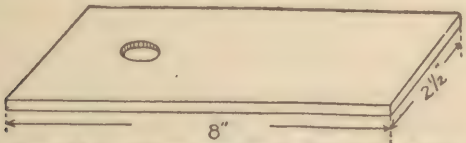

FIG. 53A.—HOW THE FROG SLIDE IS MADE

Draw one of his legs down until the webbed part of the foot comes over the hole in the board; next tie a stout piece of thread to each of his toes and then stake them out by means of pins driven in the board so that his toes will spread as far apart as they can comfort-

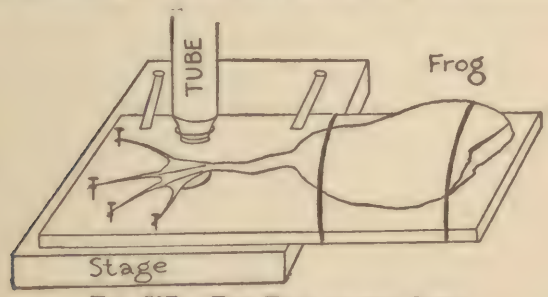

FIG. 53B.—THE FROG ON THE SLIDE

ably go, as shown at *B*. Then wet the web of his foot with a little water, and place the end of the board on the stage of your microscope and clip it securely with the spring clips; you are now ready to bring his foot into the field and to focus it, using a power from 75 to 100

diameters. You can now see the blood coming through the veins and the network of capillaries; this is due, of course, to the driving movement of the frog's heart as it beats. You will

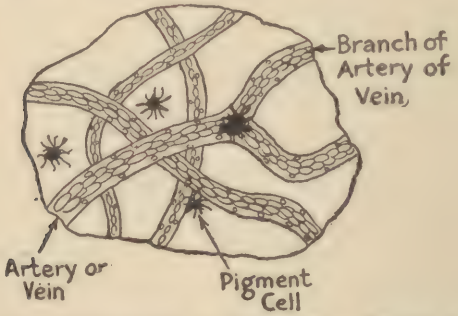

FIG. 54.—CIRCULATION OF BLOOD IN A FROG'S FOOT

also see that, while the red corpuscles move along at a rapid rate through the center of each tube, the white corpuscles move more slowly and close to the walls of the capillary tubes as shown in Figure 54.

CHAPTER XIII

ROCK, MINERAL AND METALLIC SPECIMENS

Up to this time your work with the microscope has been confined to one kind of matter only, that is, *living,* or *organic matter;* as you have seen, this consists of plant and animal life. There is, however, another great kind, or class, of matter that is found upon and in the earth's crust—in fact the earth itself is for the most part made of it—and hence it is of the greatest importance to *man* in his everyday life. This class is called *inorganic matter* since, unlike organic matter, it does not have the power to propagate itself, that is, multiply and grow. Or to say it in another way it is *nonliving* matter.

What Inorganic Matter Is Made of.—Inorganic matter in general is made up of a combination of two or more substances, each of which is of such a kind that it cannot be further separated, or *decomposed,* into other substances by any known process, chemical or otherwise. Such fundamental substances are called *elements;* of these there are two kinds,

or classes, (1) the *metals*, and (2) the *nonmetals*.

What the Metals Are.—Iron, copper, lead, zinc, tin, aluminum, silver, gold and platinum are some of the elements that are known as *metals*. When the *oxids* of metals are acted on by water the *hydroxids*, or *bases*, of the metals *are formed*, that is to say, when the oxids of metals combine with water they form *alkaline solutions*. While a few of the above-named metals are found *free* in nature, that is, in their pure state, most of them are combined with other substances.

What the Nonmetals Are.—All other elements, that is, those which are not metals, are called *nonmetals;* these include the gases, such as oxygen, chlorine, fluorine, bromine, iodine, etc., and such solids as silicon, carbon, phosphorus and sulphur. This is not a list of all the nonmetals by any means, but simply a few of the most common ones that are found in rocks and minerals.

The oxids of the nonmetallic elements when acted on by water form *acid solutions;* this chemical property distinguishes them from the metals. A few of these nonmetals are found in the free state in nature; chief among them are the oxygen in the air, carbon in coal, in graphite and in the diamond, and sulphur, which is found free in most volcanic regions.

While the metals do not combine chemically with each other, they combine readily with the nonmetals which also combine readily with other nonmetals. Compounds so formed are known as *metallic*, or *nonmetallic*, depending on whether a metal is or is not present.

What Rocks and Minerals Are.—*Rocks* and *minerals* are composed of various substances, the former usually having little or no metals in them and the latter having one or more metals mixed with the nonmetals. You should, therefore, know something of the principal compounds which are formed in this way.

What the Sulphides Are.—When a metal combines with sulphur a compound is formed that is called *sulphide*, and thus we have such minerals as *zinc sulphide*, or *sphalerite* to give it its mineral name; *lead sulphide*, or *galena; copper sulphide*, or *chalopyrite; iron sulphide*, or *pyrites*, etc.

What the Oxides Are.—When a metal or a nonmetal combines with oxygen, a compound is formed that is called *oxide*. Thus when iron combines with oxygen, *iron oxide* is formed; this is commonly called *iron rust*. Minerals that are oxides are *quartz*, or silicon dioxide; *hematite*, or iron sesquioxide; *cuprite*, or copper oxide; etc.

What the Halides Are.—The nonmetallic gaseous elements called chlorine, bromine, iodine

and fluorine are known as the *halogens,* and when these combine with the metals they form substances called halides, that go by the name of chlorides, bromides, iodides and fluorides; thus the mineral *halite* is sodium [1] chloride, that is, common table salt; the mineral *fluorite* is calcium [2] fluoride, etc.

What the Carbonates Are.—Carbon combines very easily with oxygen and when it does so *carbon dioxide* is formed. This is a nonmetallic compound and when this combines with a metallic compound minerals that are called *carbonates* result, as for instance, *calcite,* which is calcium carbonate; *cerussite,* or lead carbonate, etc.

What the Silicates Are.—When silicon[3] and oxygen combine they form *silicon dioxide,* which is a nonmetallic compound, and, when this combines with some of the metals, a group of minerals known as the *silicates* is formed; to this group belongs most of *igneous,* or fire-formed rocks, such as *granite,* since great heat is needed to bring about this combination.

What the Phosphates Are.—These minerals are compounds of the *oxides of the metals* with *phosphorous,* which is a nonmetallic element;

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[1] Sodium is a metal.

[2] Calcium is a metal.

[3] This is a hard, colorless crystalline compound which is found pure in many rocks and sands.

they are usually the *secondary* products produced by the alteration, or chemical change, which has occurred in other minerals. The mineral known as *apatite* is one of the most common forms and is the combination of calcium fluoride and the double oxide of phosphorus.

What the Sulphates Are.—These minerals are formed in much the same way as the phosphates and are *secondary* products. The chief sulphates are *anglesite,* or lead sulphate; *barite,* or barium sulphate; and *gypsum,* or calcium sulphate. While there are a great many other groups and combinations of metals and nonmetals to form minerals these are the main ones which you ought to get clearly in your mind so that you will know what you are about in your examination of rock, mineral and metallic specimens.

The Structure of Rocks, Minerals and Metals.—All rocks, minerals and metals have one of two kinds of forms or structures: (1) the *amorphous,* and (2) the *crystalline.*

The Amorphous Form.—Those elements and substances which have no definite internal form or structure are called *amorphous.* Carbon, when in the form of graphite, is *amorphous,* and so is sulphur under certain conditions.

The Crystalline Form.—This form, or structure, is definite and all of the minerals named above are found in this state as well as carbon,

which, as you have just seen, is amorphous in graphite, and crystalline in coal and in the diamond. The formation of crystals of various substances and compounds is of great importance in microscopic work; you should therefore have a clear general idea of crystalline forms and their causes.

Crystals and Their Systems.—The chief conditions under which compounds take on a crystalline form are (1) when they pass from a gaseous or a liquid state into a solid state, as, for instance, the crystals which are formed in iron when it cools from a liquid, or molten, to a solid state; and (2) the *evaporation*, or *dehydration*,[4] of a chemical solution, that is, the removal of the water from the solution.

Crystals are usually produced very slowly, and the outward form of a crystal is simply an enlargement of its interior structure, since it is built up by the growth of one layer upon another. There are six different kinds, or types or *systems*, as they are called, into which crystals form. These follow:

The Regular or Isometric System.—In this system the crystals have three *axes*,[5] all of which are of equal length and at right angles to each other, such as the cube as shown at *A* in Figure 55. This is the form that *sodium*

[4] To deprive of water.
[5] The plural of *axis*.

chloride, which is common table salt, crystallizes in.

The Square Prismatic System.—In this system, which is also called the *tetragonal system,*

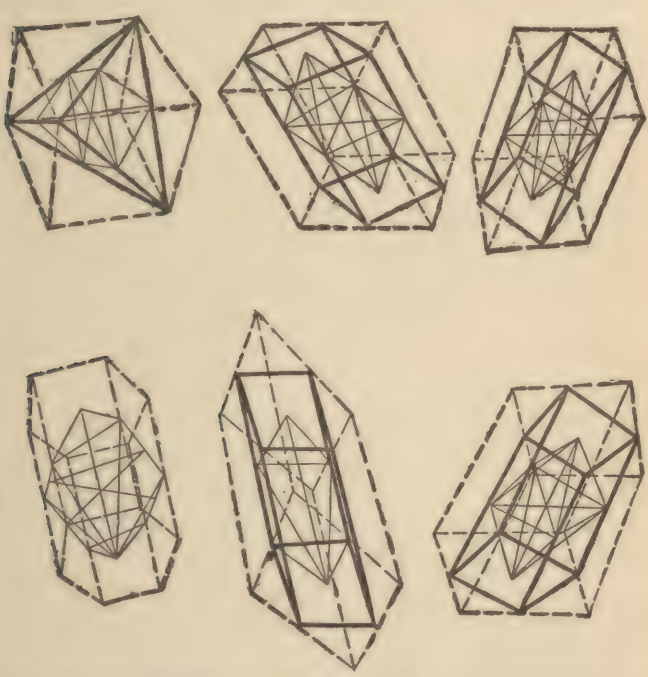

FIG. 55.—CHARACTERISTIC SYSTEMS IN CRYSTALLIZATION OF MINERALS

the crystals are longer in one direction than in the others, and have either a four- or an eight-sided cross section and three axes that set at right angles to each of the other two, which

are equal in length as shown at *B*. *Zirconium silicate* crystallizes in this system.

The Hexagonal System.—In this system the crystals are elongated in one direction and have either a three- or six-sided cross section and four axes, three of which are in the same plane, as shown at *C*. *Marble* crystallizes in this system.

The Rhombic System.—In this system, which is also called the *orthorhombic system,* the crystals have a *rhombic* cross section, that is, they have three axes all of which are of unequal length and at right angles to each other as shown at *D*. Sulphur often crystallizes in this form.

The Monosymmetric System.—This is also called the *monoclinic system.* The crystals of it have three axes of unequal length, two of them being at right angles to each other as shown at *E*. *Gypsum* crystallizes in this form.

The Asymmetric System.—In this system, which is also called the *triclinic system,* the crystals have three unequal axes, none of which are at right angles to one another, as shown at *F*. *Copper sulphate* crystallizes in this form.

It will be well worth your while to get the above systems of crystals clear in your mind; when you do so you will find that, with the aid of your microscope, you will have no great

trouble in identifying any that you may have occasion to examine.

The Polarization of Light.—As you have already learned in Chapter III, light travels in the form of *waves* set up in the *ether*, and the *wave front* is always at *right angles* to the ray of light, which is made up of a large number of such waves, and is moving. You have also seen how certain substances, such as prisms of glass retard light waves and cause the light to be bent, or *refracted,* out of its course, and split up or dispersed, into its component colors.

In a like manner certain substances such as *calcite,* or *Iceland spar,* as it is commonly called, have the property of dispersing the ray of light into two separate and distinct rays whose wave fronts advance in planes that are at right angles to each other; this phenomenon is known as the *polarization of light.*

If these rays are now passed through a second prism, each of them will be refracted to a different degree, and if the refraction of one as against the other is great enough, you will see two separate and distinct images of the object. This is based on the same principle as the colors of light wave in a lens, all of which I have explained in Chapter III.

What the Polariscope Is.—When two prisms of *calcite,* that is, *Iceland spar,* are cemented together with a layer of *Canada balsam,* the

double prism thus formed acts on a ray of ordinary light like this: when the light is polarized, as explained above, one of the rays so formed passes through the two prisms unchanged; this ray is called the *polarized,* or *extraordinary ray.*

The other ray of light, which is known as the *ordinary ray,* is very greatly refracted when it

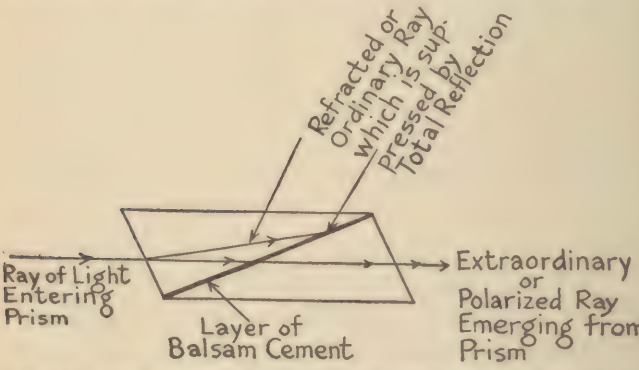

FIG. 56.—HOW A NICOL PRISM POLARIZES AND SUPPRESSES LIGHT RAYS

passes through the first of the two prisms, in fact, so much so that by the time it reaches the layer of balsam its angle of incidence is so great that it causes it to be *totally reflected.* The result is that the ordinary ray of light does not pass through the second prism at all, and hence, only one ray, that is, the polarized ray, emerges from the prism as shown in Figure 56.

Such a combination of prisms is known as

Nicol prisms, or just *Nicols* for short, after the man who discovered their action; they are of great importance in the examination of rocks and mineral specimens in which there are usually some crystalline forms present.

What the Micropolariscope Is.—This instrument is an adaptation of the Nicol prism to the microscope so that the light reflected from the mirror of the latter will be polarized, and the ordinary ray will be repressed, that is, held back and only the polarized ray will pass up and through the object and the objective of the instrument.

In its simplest form the *micropolariscope* consists of a Nicol prism mounted just above the mirror and under the stage of the microscope; this is called the polarizer. Another Nicol prism, called the *analyzer,* is mounted in the tube just above the objective; both of these prisms and the stage are so made that they can be turned to any desired position.

How the Micropolariscope Works.—Now the action of the polarizer and the analyzer is the same as that of the ordinary polariscope described above, when they are in one of two positions, that is, (1) when their oblique surfaces are parallel, and (2) when these surfaces are 180 degrees from the parallel position, that is, when they are in a line with each other. In both cases the ordinary ray of light is suppressed;

in other words, cut off entirely from the eye, while the ray of polarized light reaches the eye unchanged.

If, on the other hand, you turn the prisms so that their oblique surfaces are at right angles to each other, that is, 90 degrees from the parallel position, no light at all will reach your

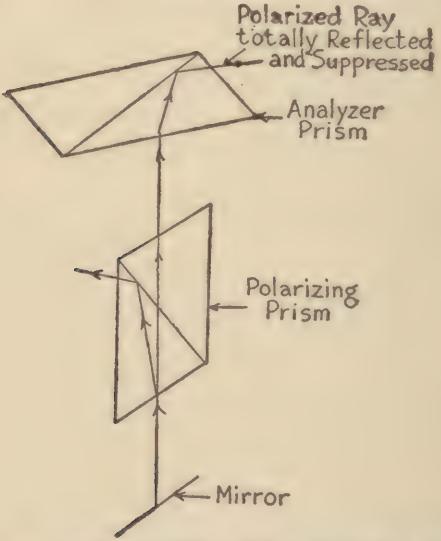

FIG. 57.—HOW CROSSED NICOLS SUPPRESS LIGHT

eye, for the second, or analyzing, prism suppresses the polarized ray of the first prism in exactly the same manner as the first prism suppresses the ordinary ray, and in this position there will be complete darkness, as shown in Figure 57.

But when you turn the prisms to positions halfway between 180 degrees (or 90 degrees), you will find that the polarized ray of the first prism is broken up into two rays, one of which is polarized and the other, ordinary; further, the polarized ray will pass through the analyzer prism and the ordinary ray will be suppressed as before.

The Action of Polarized Light on Minerals.—When the prisms are crossed, that is, turned so that their oblique surfaces are at 90 degrees to each other and a crystal of the *regular system* is placed on the stage of your microscope, all the light is cut off just as it was before you inserted the crystal, because all amorphous substances and crystals of the regular system do not polarize the light that passes through them.

If, however, the prisms are crossed and a crystal belonging to any of the other systems is placed on the stage, the crystal will become *Luminous,* since crystals which form in these systems have the property of polarizing light that passes through them. The action of these crystals on light is this: the polarized ray of light which passes through the polarizing prism is in turn broken up by the crystal on the stage, when two rays of light, which are polarized at right angles to each other, will emerge from it.

In the extraordinary, or polarized, ray, the light waves are not in the same plane as that

set up by the light waves which are suppressed by the analyzer prism, while the other ray whose light waves are in the same plane as those light waves which are suppressed by the ana-

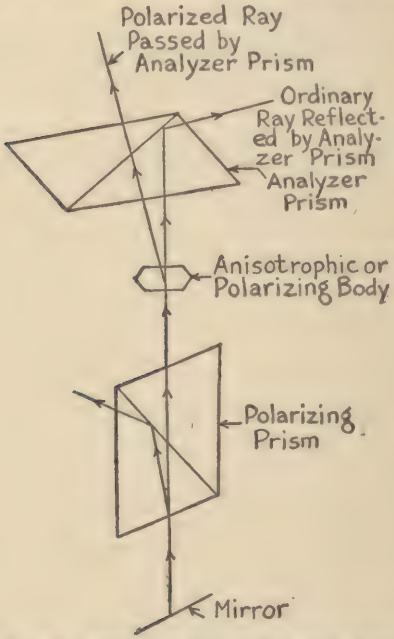

FIG. 58.—HOW AN ANISOTROPIC BODY ACTS UNDER CROSSED NICOLS

lyzer prism, that is, the ordinary ray, is totally reflected, as shown in Figure 58.

How to Analyze Crystals with the Polariscope.—Crystals of the regular system which are nonpolarizing are called *Isotropic*[6] bodies

[6] This word means having the same properties along lines in every direction.

and do not become luminous when viewed with crossed Nicol prisms, while those of other systems which become luminous when viewed with crossed Nicol prisms are called *Anistropic*[7] bodies.

How to Identify Crystals by Extinction Angles.—You can tell crystals that belong to the square prismatic, hexagonal and rhombic systems from those of the monosymmetric and asymmetric systems by the difference in the directions of the waves of light that pass through them, and you can determine the directions of these light waves in this way.

Place the crystal you want to examine under the crossed Nicol prisms and observe the position at which it becomes *dark* when you turn the stage of the microscope; this point is called the position of *extinction,* and it shows that the wave fronts of the light waves coincide, that is, are even with, the planes of the Nicol prisms, and the angle which is formed in turning the stage to this position is called the *angle of extinction.*

If this angle is 0 or 90 degrees it shows that the crystal belong to one of the three systems named above, and these systems are said to show *symmetrical extinction.* If an angle larger than 0 or 90 degrees is neccessary in order to

[7] This word means having different properties along lines in different directions.

obtain extinction, or darkness, then the crystal is of the nonsymmetrical, or asymmetrical, system.

How to Identify Crystals by Converging Polarized Light.—Still another way to identify crystals is by means of *convergent polarized light;* this is produced by placing a converging lens over the polarizer. When this arrangement is used, dark rings and crosses called *interference figures* are produced.

Crystals that belong to the square prismatic and hexagonal systems have one axis along which the ray of light passes unchanged because of the *homogeneous* [8] nature of the structure of such crystals about this axis; therefore, these are called *uniaxial systems.* Crystals of the other three anisotropic systems, that is, the rhombic, monosymmetric and asymmetric, have two of these axes along which light passes unchanged, called *biaxial* crystals.

When uniaxial crystals are examined with converging polarized light, the interference figures will be circular and will show straight bars which will follow the figures when the stage is turned. The bars presented by biaxial crystals will, however, be curved and the interference figures will be *elliptical;* and when the stage is rotated it will move in the opposite di-

[8] This means uniform, that is, made up of the same material and structure throughout.

rection to that in which the elliptical interference figure moves, as shown in Figure 59.

How to Identify All Kinds of Crystals.—By using all the various effects produced by the micropolariscope which I have just described, you can identify the system, that is, find out the one to which any crystal belongs, and the way to go about it is this:

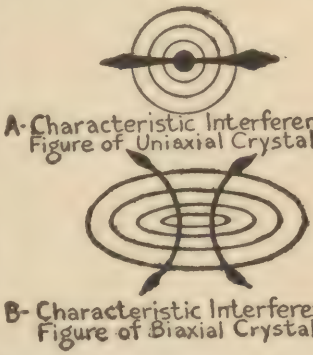

FIG. 59.—INTERFERENCE FIGURES WITH CONVERGENT POLARIZED LIGHT

The Regular System.—Crystals of this system are *isotropic,* that is when you examine them with crossed Nicol prisms they remain dark, and, as a consequence, do not show any interference figures.

The Square Prismatic System.—Crystals belonging to this system show *uniaxial interference figures* and *symmetrical extinction.*

The Hexagonal System.—Crystals of this system show uniaxial interference figures which are three- or six-sided and which exhibit *symmetrical* extinction.

The Rhombic System.—Crystals of this type show *biaxial* interference figures with *symmetrical extinction.*

The Monosymmetric System.—Crystals of this system show *biaxial interference figures,* but extinction, that is, symmetrical, in one zone only, all others having *extinction angles* only.

The Asymmetric System.—Crystals of this order show *biaxial interference figures* with extinction angles in all zones.

The Microscopic Examination of Metals.—The examination of metals under the microscope, or *metallography,* as it is called, is of great importance in everyday commercial life. A section of the metal to be examined is first carefully polished with *emery* and *jeweler's rouge,* then it is covered with a solution of ammonia in water; this etches the surface of it slightly and so brings the structure of the metal out into relief. This done the specimen is examined by reflected light as described in Chapter IV on illumination. In this way the impurities of a metal can readily be seen and the structure and hardness of a metal can be learned.

CHAPTER XIV

EXAMINATION OF HOUSEHOLD OBJECTS

While all the foregoing objects are interesting and highly instructive there is still another class that you should examine with your microscope and which will prove very profitable. In this class objects that are common to everyday life, and particularly in the household, as the clothes you wear, the paper you write on, the food you eat, the water you drink, and so on.

Examination of Fabrics.—The fabrics of which your clothes are made are woven of threads, the goods varying in thickness, strength and flexibility, depending on the nature of the threads that form the woof and warp. The threads themselves are made up of long fibers, either spun or twisted to make them finer and stronger, obtained from both plants and animals. There are five chief classes of fibers which are used for making fabrics: (1) *flax,* (2) *cotton,* (3) *wool,* (4) *silk,* and (5) *artificial silk.*

Flax Fibers and Linen.—One of the most prized of the plant textiles because of its

great strength, wearing qualities and beauty is woven from threads which are spun from the long *Bast* fibers obtained from a plant called *flax*. This plant is largely cultivated for the purpose in both the Old and the New World.

In preparing the best fibers for use, the stems of the plant are fermented in water: this is called *retting*. Retting dissolves the sticky substances which hold the tissues of the stem together. Now the bast fiber is the layer of fiber which grows on the under side of the bark of the *dicotyledon*[1] plant; after they have been properly *retted* the stems are *scutched*, that is, they have their outer and inner tissues broken up by *beaters*, when the bast fibers are left behind in the form of bundles.

If you will now look at one of these fibers with your microscope, you will see that they are formed of elongated cells, each of which has a canal in the center. This canal was, during the life of the plant, filled with protoplasm, which was gradually converted into the material of which the plant is made, leaving only the cell walls of *cellulose*[2] behind. These cells have a characteristic size, being about 0.30 *millimters*[3] long, and 0.02 *millimeters* in diameter; you

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[1] See Chapter IX.

[2] Cellulose is an amorphous white compound that is *isometric* with starch. It forms the fundamental material of plants.

[3] A millimeter is equal to 0.03937 of an inch. It is the smallest division in the *Metric System* of measures of length.

will also know them by the swellings which are found around them. A flax fiber is shown at *A* in Figure 60.

Cotton and Cotton Fibers.—One of the cheapest and most useful of the textile fabrics is a *vegetable hair* which is formed on the seed of the cotton plant—to enable the seed to be carried along by the wind after the seed capsule, or cotton boll, as it is called, has burst open.

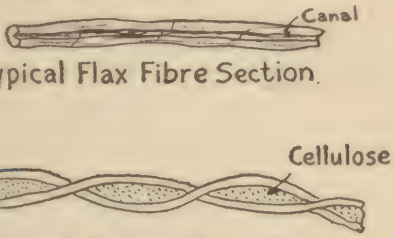

FIG. 60.—SOME VEGETABLE FIBERS

Cotton grows well in all parts of the world where the climate is mild and where there is an even supply of moisture. The cotton fibers which are attached to one end of the cotton seed must first be torn off, or *ginned*, so that they can be spun into thread.

Now examine a cotton fiber under your microscope and you will see that it is formed chiefly of cellulose and that this is covered with a skin, or *cuticula*, of other material. The general shape of the fiber is that of a twisted hollow ribbon, having a central canal whose walls are

very sharply outlined. The cross section of the cotton fiber is either shaped like a crescent or is elliptical, and the fibers vary in length from 20 to 40 millimeters, all of which is shown at *B*.

Wool Fibers and Fabrics.—Wool is the fleecy hair of the sheep and is highly valued as a textile product. You have already seen in Chap-

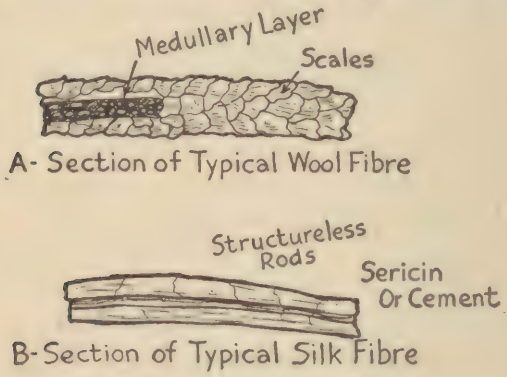

FIG. 61.—SOME ANIMAL FIBERS

ter XII something of the general structure of the hairs of animals when examined under the microscope. Wool, like other animal hairs, is made up of an axis, or central part, called the *medullary layer*, which consists of cells that have a more or less rounded form. Around this axis is the tougher structure of the hair which is built up of elongated and flattened cells known as the *cortex*, and, last of all, this is covered with a layer of *imbricated*, that is, lap-

ping, scalelike cells, as shown at *A* in Figure 61.

These scales are useful in determining the amount of wool in a fabric for you cannot mistake them. Further, the scales add greatly to the strength of a fabric that is made of wool hairs, for they project from the latter in such a way that when two or more of the hairs are twisted, the scales interlock with one another, thus providing a fabric of great strength and wearing qualities as well as of great warmth. These hairs are spun into yarn and this in turn is woven into fabrics.

Silk and the Silkworm.—Silk is also a fabric that is woven of animal fibers, but it is very different from wool, for, instead of being a hair textile, it is a secretion produced by the glands of a worm known as the *silkworm.* This worm is brought forth from the larva of a moth called the *Bombyx mori,* and it spins a cocoon of silky threads around itself before it metamorphoses, that is, changes, into a moth. The silk is obtained from the cocoons by dipping them into hot water which kills the worm and dissolves the sticky substance that holds the threads together; it is then unwound and reeled off.

Now examine a silk thread under your microscope and you will see that it looks very much like a tube having a minute central canal. This is caused by the way in which the silk thread

is spun by the worm. The latter has two sets of glands at its head, or anterior, end, the first consisting of two spinnerets, each of which discharge a thick fluid which gets more or less hard when the air comes in contact with it; the second set discharges a substance called *Sericin* which cements the two fibers formed by the spinnerets together. It is this substance that gives the fibers the appearance of having a central canal as pictured at *B*.

Artificial Silk.—This is made either from cotton or wood pulp and therefore is a *cellulose* product. To make cellulose into artificial silk, the former is converted into a viscous solution, which is the passed while it is under pressure through glass tubes provided with fine nozzles in imitation of the spinnerets of the silkworm.

The solution emerges from the nozzles in a continuous filament, and is then treated with a chemical solution that hardens it; the filament is cut into suitable lengths, when the fibers so formed are spun into threads. You will have no difficulty in telling artificial silk from real silk when you examine it with your microscope, for the former is quite smooth and solid and shiny.

To examine a fabric, or textile, with your microscope, cut off a little piece of it and then separate the warp from the woof threads and use a low power objective. In this way you

can easily determine whether the fabric is all wool, cotton, linen, silk or artificial silk (but not whether it is a yard wide), or whatever it was represented to be when you bought it.

Examination of Paper.—Paper can be made from any fibrous material which it is possible to convert into a pulp. The chief raw materials which are used in the manufacture of various kinds of paper are (1) *straw fibers*, (2) *cotton fibers*, (3) *linen fibers*, and (4) *wood fibers*.

In preparing these fibers from the raw material for paper-making, either mechanical, or chemical, or both of these means are used to separate the pure cellulose from the gums that cement it together in the plant. This is usually done by boiling the raw material under pressure with a strong alkaline solution which dissolves the latter. The material is then bleached and passed into beaters which chop it up until a pulp results. While in this condition the *coloring matter*, *sizing* and *fillers* are mixed with it, and it is then pressed and dried between heavy rollers.

To examine a sample of paper with your microscope, tear it into bits and boil well in a weak solution of *caustic soda* which will reduce the bits to a pulp. This done, put the pulp into a fine sieve and wash it well in clear, cold water when the fibers will separate from each other. You can now either mount them or examine

them while they are still wet, although it is better to let them dry.

The first three kinds of plant fibers that I mentioned for paper-making have been described under the heading Examination of Fabrics. Wood fibers for making print paper, pasteboard, etc., while also formed of cellulose, are quite different from the former both in appearance and structure. There are two chief kinds of wood fiber: (1) the trees of the *Gymnosperm* family; and (2) trees of the *Angiosperm* family.

Structure of Gymnosperm Fibers.—As you have already seen, this group of plants includes pine, fir, hemlock, balsam and spruce. The wood pulp which is made from trees of this group consists for the most part of the fibrovascular bundles which are found in the stem. In general the cells that make up these fibers are wide and long, being characterized by the rows of oval and round pits which their surface presents. Nearly all print paper is made from Gymnosperm fibers.

Structure of the Angiosperm Fibers.—The fibers of the *Angiosperms,* that is, of the true flowering and seed-bearing plants, such as birch, willow, elm, poplar, maple, chestnut, etc., are characterized by their long and narrow fibers, and these are composed of cells that are short and have peculiar markings. These fibers

have a central canal, the walls of which are often filled with rounded and oval pores.

One of the surest ways of telling the difference between the fibers of the gymnosperms from those of the angiosperms is by the shape of the cells; these are so long in the former group as usually to exceed the diameter of the field produced by a low power objective, while those of the latter group have short cells, the ends of which are usually within the field of a low power.

Examination of Food Stuffs and Their Adulterants.—The most practical use to which you can put your mircoscope is to examine the foods and fluids that you eat and drink, for by this means you can tell whether they are adulterated or contain disease germs. This is of great importance, for a large number of foods are not at all what they seem to be when examined with the naked eye.

The Starches.—As I told you in Chapter IX the *chlorophyll* of plants changes carbon dioxide and water into *starch;* this not only nourishes the growing plant itself but is also one of the chief foods which *man* gets out of plants, and all plants contain it to some extent. Moreover, it is used for many other purposes, such as making adhesive paste and sizing for the various industries.

It is also largely used in the manufacture of

dextrins and *sugars*, by treating it with weak acides and *enzymes*,[4] and from the sugars so produced alcohol can be made. It is easy to see from this that starch is a very important compound to man in his everyday life. There are seven chief kinds of starch which you ought to examine with your microscope. These will be explained under the following subheadings:

Wheat Starch.—This is largely used as a *size* in the manufacture of fabrics since it makes a very smooth paste. The grains are more or less circular in shape, as shown at *A* in Figure 62, and may be either small or large. Like all grains of starch they are built up of concentric layers, the outside layer of which has a celluloselike structure, while at the center there is a small open space known as the *hilum*.

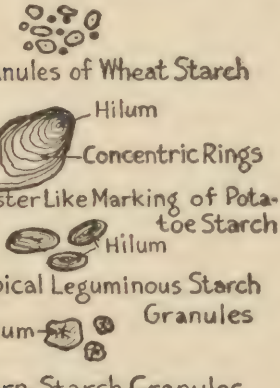

Fig. 62.—Granules of Starch

Potato Starch.—This starch is also largely used for making *size*. You can readily identify it with your microscope by its large size and

[4] An enzyme is a chemical compound of vegetable or animal origin that causes chemical transformation.

oyster-shell-like markings as at *B;* the granules are of an elliptical shape and the concentric markings show up very clearly. The *hilum* will be seen close to one end of the grain surrounded by these markings. A peculiar thing about the potato starch grain is that it has more than one hilum, and sometimes a single grain will be formed of two or more granules.

Leguminous Starches.—The starches of the plants called *legumes,*[5] such as beans and peas, also have granules of characteritsic size and shape. In general the grains of these starches are rather small and elliptical in shape, and, instead of a circular hilum, they have a long, narrow slit running lengthwise of the grain, as at *C.* The concentric markings are also very faint as compared with those of the potato starch.

Corn and Rice Starch.—These starches are used as a foodstuff as well as in the laundry, and they also serve for making dextrin and sugar. The grains are only about half as large as those of wheat starch and are *polyhedral,* that is, many sided, in shape, their characteristic feature being their sharp angles; further, and finally, their concentric layers cannot be seen. Rice starch is very like cornstarch in that the polyhedral grains have sharp angles, but you can easily tell them apart because the

[5] The *legumes* are plants that belong to the bean family.

granules of rice are exceedingly small; in fact, they occur in aggregate masses, and, in most cases, no hilum is visible.

Tapioca Starch.—These grains are obtained from the root of the *Cassava,*[6] which as it grows is a poisonous plant that contains *hydrocyanic acid.*[7] The latter is removed by the processes through which the plant goes in the making of tapioca, and nonpoisonous starch grains, which are much used as a foodstuff, are left behind. These starch grains are circular in shape, one end is slightly extended and cut off at the top, or truncated, as it is called, with the hilum in its center, and they are about the same size as cornstarch grains.

Adulteration of Foods.—One reason why you should get acquainted with the various kinds of starches is because they are largely used in adulterating other and more costly foods. Especially is this true of those food products which in themselves are of a granular nature, in which case the adulteration cannot be detected with the naked eye, or even when subjected to chemical analysis, since the chemical composition of both is identical. This being true the only certain way to detect such adulteration is with the microscope when the characteristic

[6] This is a tropical or subtropical American shrub.

[7] This is the most powerful and rapid poison known. It is a liquid compound formed of *cyanogen* combined with *hydrogen.*

features of the adulterant starch granules will stick out like a sore thumb on a baby's hand.

Besides the adulteration of granular foods with starch, there is a large variety of other substances used in similar deceits which you can easily detect with your microscope, provided you know how the food itself looks when it is in the pure state. You will find it profitable to examine such edibles and drinkables as coffee, sugar, tea, cocoa, chocolate, spices of all kinds, flour, cereals, etc., and learn the nature and proportion of the adulterant that is present if any has been used.

All manner of ground substances are used for this purpose, the most common of them being the waste parts of the plant from which the food itself is obtained, as for instance, tea stems, mustard hulls, etc. Still more flagrant are the cases of adulteration where some substance that is entirely foreign to the food is mixed with it, such as the addition of wheat and charcoal to cloves, ground olive stones to pepper, and peas, chicory, charcoal, pea hulls, wheat, etc., to coffee.

In examining a food substance of any kind named above, you should first make it into powder, taking care not to get it so fine that the characteristic structures of the tissues themselves will be destroyed. You should also examine several samples taken from different

parts of the food in order to find out whether it is of uniform quality and composition throughout.

Examining Flour and Bread.—Flour, and consequently, bread is most often adulterated with other starches, such as potato starch, or granulated bran. In either case your microscope will plainly point out the offending particles.

Butter on the Slide.—If you will examine a specimen of pure butter you will see that it is composed chiefly of globules of *fat* and smaller globules of *water*. The chief adulterant of butter is *margarine*,[8] and oils and fats of other and different kinds. You will readily detect these by the fact that the characteristic even field of pure butter is destroyed, the globules of fat being smaller and those of water larger.

Coffee on an Enlarged Scale.—The main adulterants of coffee are chicory, burnt sugar and bran. Now if you will examine a thin, longitudinal section of a real coffee bean, you will see that it is made up of thick-walled cells, the inside of which are filled with a minute granular substance in which are dispersed tiny drops of an oily substance. Further, the cells in the inside of the bean have a characteristic thickening of the walls.

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[8] This is an imitation of butter whether it contains real butter or not.

Your microscope will therefore readily show the presence of any foreign substance in coffee, provided you use a high enough power to bring out the cellular structure of it and the adulterant used. It is easy to detect *chicory*[9] by this method, for instead of the thick-knotted cell walls of the coffee bean, you will see that the walls of the former are delicate, the cells themselves being quite like those described under angiosperms.

Sugar under the Objective.—The chief adulterant of sugar when any is used, since the commodity owing to its cheapness is seldom adulterated, is starch, and in some cases even sand has been used, although this mineral substance is so easily detected that it is not often used. Your microscope will show up these adulterants very plainly.

Examination of Animal Foods.—While all meats that are intended for human consumption are examined by government inspectors, still you can make doubly sure that that which you are going to eat is all right by using your microscope on it. Animal foods may be rendered unfit for use either because (1) *preservatives* have been used upon the meat which indicates that it is not fresh, or even worse, that

[9] This is the common adulterant of coffee and is sometimes used as a substitute for it. It is the roasted and pulverized root of an herb of Europe which has been naturalized in the United States.

it has not been freshly killed but died on the hoof; if this bad state of affairs existed you can tell if the animal was diseased, or (2) if it contains parasitic worms which are likely to be injurious if eaten.

The Use of Preservatives.—The most common preservatives that are used are salt, borax and niter, and, since all these substances are

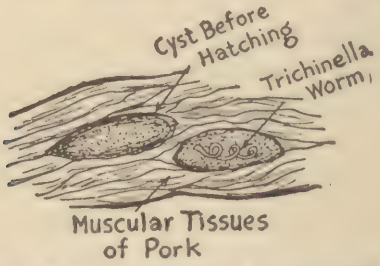

FIG. 63.—HOW PARASITES APPEAR UNDER THE MICROSCOPE

of crystalline structure, they will show up as bright spots under the microscope due to the passage of light through them.

Parasites under a Low Power.—There are a large number of parasites which become embedded in the muscles of living animals, and which encyst themselves in the body of *man* if he is so unfortunate as to have eaten meat which is thus infected.

These parasitic worms, among the most common of which are the *Trichina Spirals* found in the muscles of swine and the *Cystercus Hovis* found in cattle may develop cysts in man that

eventually will kill him. You can readily locate them in the flesh of the animal with the aid of a microscope, as they are spindle-shaped, whitish bodies as shown in Figure 63. The *Trichina* worm itself is coiled up inside the cyst.

Germs under a High Power.—Germs, or more properly bacteria, are microscopic vegetable organisms. The most dreaded disease germs found in animals are those which cause tuberculosis. These germs are embedded in the tissues of the various organs or other parts of the body, and in the case of cows are often found in the milk they give. If you will examine either the flesh or the milk under a high enough power you will see them, if they are present, in the form of very minute, rod-shaped fungi, as shown in Figure 64.

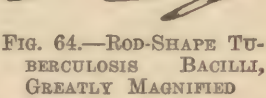

FIG. 64.—ROD-SHAPE TUBERCULOSIS BACILLI, GREATLY MAGNIFIED

Examination of Drinking Water.—The way to find out if there are disease germs in the water you drink is to make a *culture*[10] of gelatine. To do this melt about 15 cubic *centimeters*[11] of *sterilized gelatine* in a test tube over a flame, and run into it about one cubic centimeter of

[10] Culture means (1) the process of growing and multiplying bacteria in gelatine, or some other nutrient substance, and (2) the bacteria themselves.

[11] A centimeter is a trifle longer than ⅜ of an inch, hence a cubic centimeter is a little longer than a ⅜ inch cube.

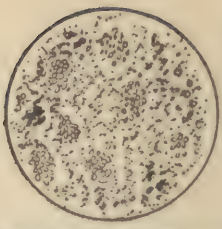

FIG. 65.—A GERM INCUBATOR AND A COLONY OF GERMS

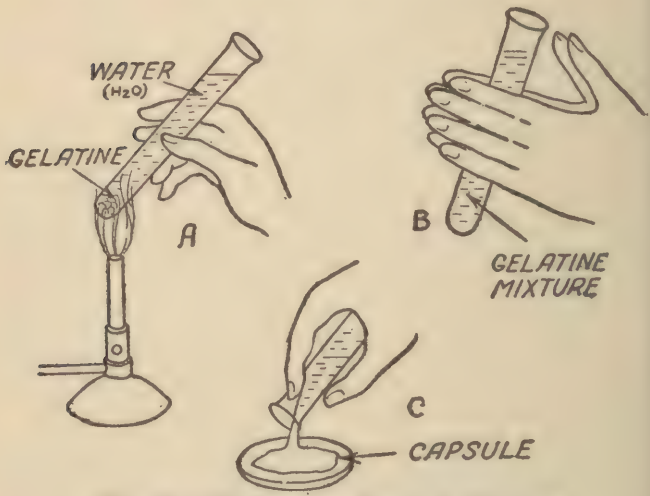

FIG. 66.—PREPARING A GELATINE CULTURE

the water you want to examine with a medicine dropper, or a *pipette,* as shown at A in Figure 65.

This done mix the water and gelatine thoroughly by rolling the test tube back and forth between the palms of your hands (see *B*), and then pour it out on a *capsule* (see *C*), that is, a small, shallow dish, while it is still in the fluid state when it will form a thin film. Now put on the cover of the capsule, set it in an oven, or incubator, as it is called (see *A*, Figure 66), and keep it at a temperature of about 40 degrees Centigrade [12] for 48 hours.

Under this treatment a single germ in the water will develop whole colonies in the gelatine as shown at *B;* and you can then see them as little white spots with your naked eye, or you can count them with a low power, or you can see what kind they are with a high power.

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[12] A Centigrade thermometer is one whose scale has 100 divisions between its freezing and boiling points.

CHAPTER XV

DRAWING, MEASURING AND PHOTOGRAPHING MICROSCOPIC OBJECTS

By this time, no doubt you have examined many objects and because of their beauty or symmetry, as in the case of the diatoms, or their curious features or instructive merit, you may want to draw or photograph them so as to have a permanent record of the way they looked. Further, you will quite likely often want to know the exact size of the object that you are looking at and also the magnifying power of your microscope.

What the Camera Lucida Is.—The first thing that is needed to draw a picture or reproduce what you see when you are examining an object in the microscope is some kind of a device by which the magnified image of the object can be projected on a sheet of paper. With such a device you can trace the image with a pencil and later ink it in and color it if you care to.

A device for this purpose is known as the

camera lucida, and as there are quite a number of modifications of it, I will tell you about the Abbe type of camera lucida pictured in Figure 67, because it is one of the simplest and gives very satisfactory results. It consists of a system of mirrors so arranged that when the device is slipped over the eyepiece of the microscope the rays of light reflected from the sheet of paper laid beside the instrument are reflected

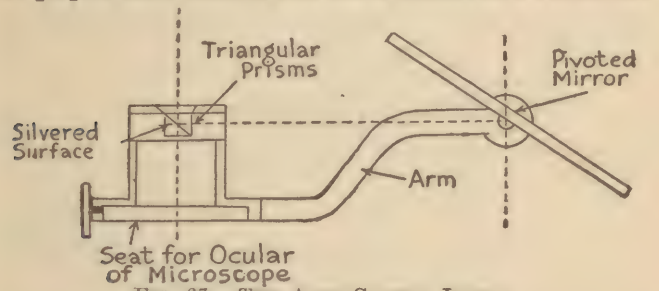

FIG. 67.—THE ABBE CAMERA LUCIDA

up and through it, and your eye sees it as though both the paper and the image of the object viewed were at one and the same place. As a result the image as seen through the camera lucida is thrown on the paper when you can easily trace it.

Now look at Figure 68, which shows how the camera lucida is operated and works. A cube is formed of two triangular prisms with a silvered surface between them, and through the latter is a hole or opening. The whole arrangement is then fitted over the eyepiece of your

microscope. To the tube is fixed an arm which carries at its free end a pivoted plane mirror which can be turned about.

The rays of light through the mirror pass up through the opening in the silvered surface of

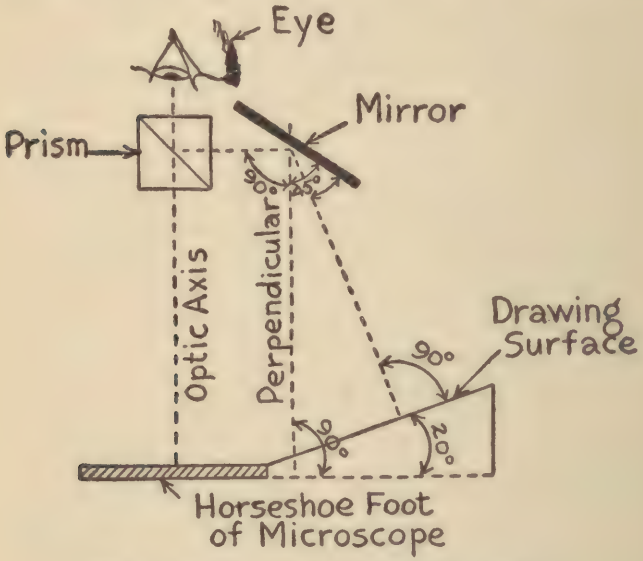

FIG. 68.—HOW THE CAMERA LUCIDA WORKS

the prisms and into your eye. The mirror on the arm is at an angle of 45 degrees with the surface of the paper that is placed beside the microscope, and the light rays coming from the paper are reflected from the surface of the mirror into the cube, where the silvered surface

acts as another mirror and reflects them up and into your eye.

In using the camera lucida it is necessary to set the mirror at an angle of 45 degrees with the surface of the paper you are going to draw on. Because of the way in which the horseshoe stand of your microscope projects, you will find that in order to get this angle you must make or have made an inclined board on which to tack your drawing paper.

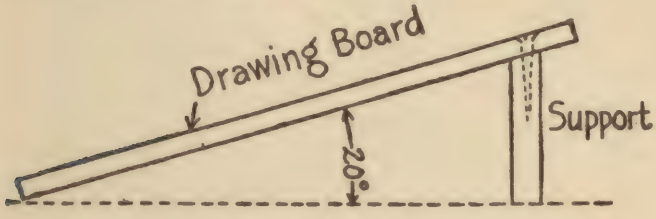

FIG. 69.—HOW THE DRAWING SUPPORT IS MADE

This is easily made from a strip of pine one inch thick, three inches wide, and ten inches long. Get a smooth board ½ or ¾ inch thick, 10 inches wide and 12 inches long, bevel one edge of the strip so that when one end of the board is laid on it the latter will be at an angle of 20 degrees with the top of the table, and then screw the strip to the board. When finished, the inclined drawing board will look like Figure 69.

Now place the drawing board as close to the base of your microscope as you can get it and

fasten a sheet of paper on the board with thumb tacks; finally, adjust the mirror of the camera lucida so that it sets at an angle of 45 degrees with the table top, which will make it equal to 35 degrees to the inclined surface of the paper on the drawing board.

Of course you must first focus the object with the greatest care and precision. You will find there is a knack in using the camera lucida, but this you will acquire with a little practice. The lighting of the object itself and of the paper on which you are drawing is of great importance, for, should the paper be illuminated too brightly, you will see the image of the paper only, and that of the object not at all, while the reverse will result if the object is too brightly illuminated for the image of paper cannot then be seen.

How to Measure the Magnification of an Object.—If you want to find out how many times your microscope magnifies an object, you will have to use a camera lucida of slightly different construction from the one described above. This is known as *Beale's* camera, and consists of a piece of tinted glass placed at an angle of 45 degrees to the optical axis of the microscope, and in the path of the pencil of rays that emerge from the eyepiece.

The paper and pencil, which are placed exactly under this inclined piece of tinted glass,

are seen by the eye directly through it, while the magnified image of the object is reflected upon the eye by the first surface of the glass as shown in Figure 70. This gives the illusion of the image being projected directly on to the paper on which you are going to draw.

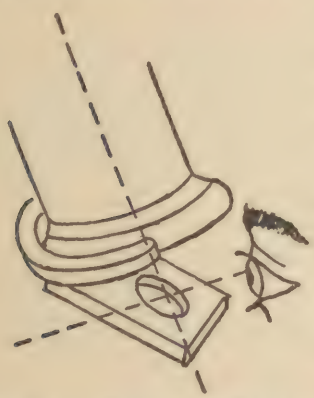

FIG. 70.—BEALE'S CAMERA LUCIDA FOR DETERMINING MAGNIFYING POWER

Now the simplest way to measure the magnification of the image of an object is to use a *Beale's camera* in combination with what is called a *stage micrometer.* This latter instrument in its simplest form consists of a piece of glass that has a scale of 100 lines to the millimeter ruled on its surface with a diamond point.

The way this instrument is used is this: set the cemera ludcia on the eyepiece of your microscope and place the glass micrometer scale on the stage. Now illuminate it with an oblique light so that the lines will be brought out clear and strong, and then trace a number of the consecutive graduations on the paper which should be at a distance of 25.4 centimenters [1]

[1] This is equal to 10 inches.

from the eye, and in a plane at right angles to the line of sight. You are now ready to measure the spaces you have traced on the paper with a scale graduated with lines 1 millimeter apart; by so doing you can find the length of the magnified image which you have traced, and hence the magnification of the micrometer scale on the stage of the microscope.

For example, suppose the magnified image of the object is 2/100 millimeter on the micrometer on the stage of the instrument, and that this spans 8 millimeters on your enlarged scale, then

$$.02 \text{ mm.} : 8 \text{ mm.} = 1 \text{ mm.} : X \text{ power}$$

or

$$X = \frac{8 \times 1}{.02} = 400 \text{ diameters.}$$

From this you will see that a drawing made under these conditions will be 400 times as large as the object which is on the stage.

How to Photograph Microscopic Objects.— Where you want to get an absolutely true and permanent likeness of a microscopic object you can do so by photographing the enlarged image with a camera. While it is perfectly feasible to use an ordinary camera for this purpose the best results are naturally obtained with an outfit made especially for photomicrographic work as shown in Figure 71.

In its simplest form an outfit of this kind consists of a microscope mounted on a heavy metal base; this has an upright metal rod, or

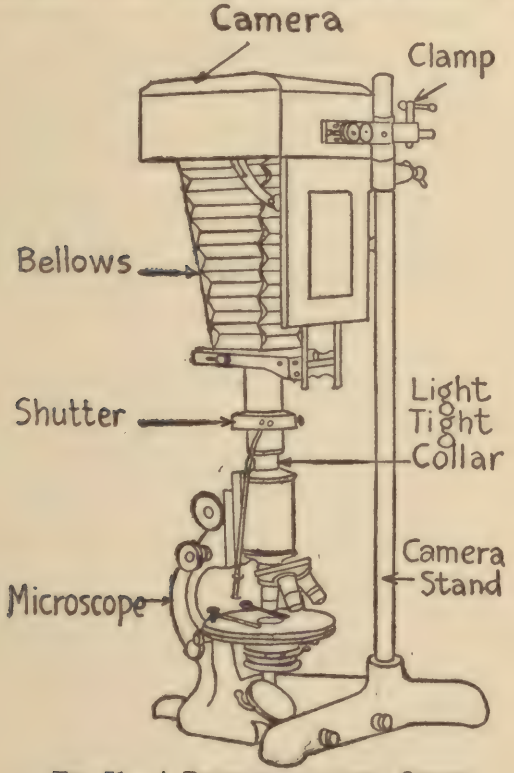

FIG. 71.—A PHOTOMICROGRAPHIC OUTFIT

standard, mounted on it to support a small camera. The latter can be turned around on the rod to align it with the microscope or turned out of the way when you want to examine the

object visually. A light-tight sleeve provides the coupling between the ocular of the microscope and the camera lens.

For photomicrographic work you will find that sunlight gives the best lighting effects and that the camera must be arranged so that it will be free from all vibration. Further, you must take exceeding pains to focus the object sharp before photographing it, and you will find that a specimen which is formed of different structures will photograph better if it is stained.

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